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Flood Control Channels Research Program

Modification of the Ackers-White Procedure to Calculate Sediment Transport by Size Fractions

by *Alan L. Prasuhn*
South Dakota State University

WES

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Prepared for Headquarters, U.S. Army Corps of Engineers

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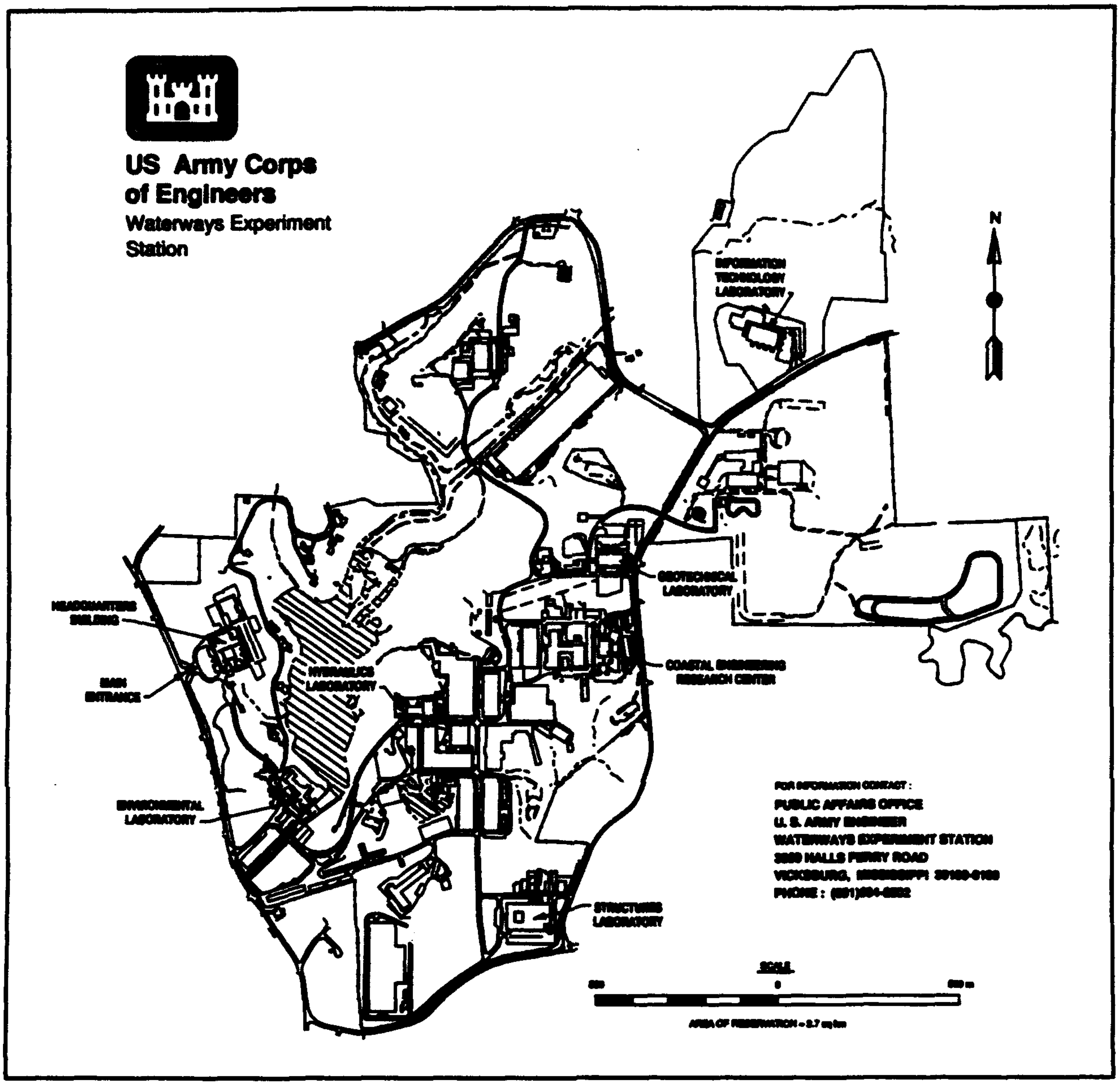

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Contents

Preface

The investigation reported herein was conducted for the US Army Engineer Waterways Experiment Station (WES) under Contract No. DACW39-89-K-0018 by Dr. Alan L. Prasuhn, South Dakota State University, Brookings, SD, under Work Unit 32552, "Sediment Transport in Small Channels," of the Flood Control Channels Research Program of the US Army Corps of Engineers Civil Works Research and Development Program. It documents modifications to the original Ackers-White sediment transport function to allow for multiple grain sizes, to include the new routine in HEC-6, and to increase the number of grain size classes into the cobble-boulder range.

The study, conducted during the period 1989 to 1990, was under the general supervision of Messrs. F. A. Herrmann, Jr., Director of the Hydraulics Laboratory; Mr. R. A. Sager, Assistant Director of the Hydraulics Laboratory; Mr. M. B. Boyd, Chief of the Waterways Division, Hydraulics Laboratory; and under the direct supervision of Mr. W. A. Thomas, Research Hydraulic Engineer, Waterways Division. This report was prepared by Dr. Prasuhn as part of the contract, and was reviewed by Mr. Thomas, who was the Contracting Officer's Representative.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measure

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
degrees	5/9	Celsius degrees or kelvins[1]
feet	0.3048	metres
tons (2,000 pounds, mass)	907.1847	kilograms

[1] To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9)(F - 32). To obtain Kelvin (K) readings, use: K = (5/9)(F - 32) + 273.15.

1 Introduction and Procedures

The purpose of this report is to indicate what has been accomplished concerning the modification of the Ackers-White sediment transport procedure and its incorporation into HEC-6. The original proposed changes to the Ackers-White procedure will be considered. These will be followed be a discussion of the initial problems that arose when the modified Ackers-White procedure was incorporated into HEC-6. Finally, the procedure that evolved as a result of the above difficulties and recommendations concerning their use in HEC-6 will be presented.

The original Ackers-White procedure (1973) has been thoroughly discussed in the literature, e.g., Prasuhn, Lewandowski, and Bagherzadeh (1987). The development, other than that necessary to explain the modifications, will not be repeated here.

In addition, the HEC-6 code was expanded to include five additional sediment sizes (from small cobbles up to and including large boulders). This will be covered first and in a fairly brief fashion.

2 Expansion of HEC-6 to Include Five Additional Sediment Sizes

The existing HEC-6 code will handle 15 size fractions of sediment (U.S. Army Engineer Hydrologic Engineering Center 1977). The research proposal included the expansion of that code to include small and large cobbles. Consistent with the format which addressed the sand and gravel sizes in groupings of five sizes, the expansion actually includes three additional sizes: small boulders, medium boulders, and large boulders. Subsequent to that report a complete listing of all the required changes and where they occur in HEC-6, subroutine by subroutine, has been furnished. They were also highlighted in a copy of the computer program.

The expanded program now accommodates the five additional sizes and the printout should be consistent with all previous procedures. The dredging routines, $DREDGE, $SED, $VOL, and perhaps some of the other special options, however, were not thoroughly tested. There should be no operational problems. The print format should be checked, however. The program will now handle 20 size fractions of sediment: one size of clay, four sizes of silt, five sizes sand, five sizes of gravel, small and large cobbles, and small, medium and large boulders. It still remains, of course, to find a transport function for the large sediments. It is felt that transport of at least the cobble sizes are acceptable using this procedure, the Schoklitsch procedure, and maybe the Meyer-Peter and Muller procedure.

The program has been tested with many combinations of sizes up to the maximum. This included tests with both four and less than four silt sizes. Changes to the format statements have been avoided with few exceptions. The E-level printout which gives all the Ackers-White parameters did not provide enough room for large values of D_{gr}. This column has been changed, but the headings (VF, F, etc.) need adjustment too as they are inconsistent with the cobble and boulder designations.

Whereas there are several sediment transport functions that may be able to give a reasonable estimate of the cobble transport, there is almost no verification of boulder transport. If HEC-6 is used for the transport of boulders, care should be taken to consider the reasonableness of the results. This expansion of the code will not be discussed further in this report.

3 Original Ackers-White Procedure (Summary)

According to Ackers and White (1973), the sediment transport depends upon a mobility factor F_{gr} given by the following expression

$$F_{gr} = \frac{u_*^n}{\sqrt{gd_s(s-1)}} \left[\frac{V}{\sqrt{32}\ \log(\alpha y/d_s)}\right]^{1-n} \tag{1}$$

Here s is the specific gravity of sediment particles, U_* = the shear velocity, g is the acceleration of gravity, V is the average velocity, y is the depth, d_s is the representative grain diameter (assumed by Ackers and White to be the d_{35} sizes), α is the rough turbulent flow coefficient (assumed by Ackers and White to equal 10), and n is a factor reflecting the sediment size. For $D_{gr} > 60$, $n = 0$, otherwise .

$$n = 1.0 - 0.56 \log D_{gr} \tag{2}$$

The dimensionless grain size, D_{gr} is given by

$$D_{gr} = d_s[g(s-1)/v^2]^{1/3} \tag{3}$$

where v is the kinematic viscosity.

The dimensionless transport G_{gr} is then calculated from the mobility factor according to

$$G_{gr} = C(F_{gr}/A - 1)^m \tag{4}$$

where the coefficient C, the exponent m, and the initiation of motion parameter A are all determined by regression analysis as follows:

Transition range ($1 < D_{gr} < 60$)

$$\log C = 2.86 \log D_{gr} - (\log D_{gr})^2 - 3.53 \tag{5}$$

$$m = 9.66/D_{gr} + 1.34 \tag{6}$$

$$A = 0.23/\sqrt{D_{gr}} + 0.14 \tag{7}$$

Coarse range ($D_{gr} > 60$)

$$C = 0.025 \tag{8}$$

$$m = 1.50 \tag{9}$$

$$A = 0.17 \tag{10}$$

The resulting dimensionless transport G_{gr} is related to the concentration X (in lb sediment/lb water, or N sediment/N water), by

$$G_{gr} = (X/s)(y/d_s)(u_*/V)^n \tag{11}$$

The actual sediment transport may then be determined by either

$$G_{gr} = (43.2)Q\gamma X \qquad (tons/day) \tag{12}$$

or

$$G_{gr} = Q\gamma X \qquad (N/s) \tag{13}$$

The resulting sediment transport is consequently the total bed material load based on the representative size. It was not suggested by Ackers and White that their procedure could be used to calculate the transport by size fractions.

4 Modifications to the Ackers-White Procedure (Prasuhn Procedure)

The original proposal to modify the Ackers-White proposal has been presented and discussed on several occasions (Prasuhn, Lewandowski, and Bagherzadeh 1987; Heng 1989; Prasuhn and Heng 1990). In its final form it may be summarized as follows.

In their procedure, Ackers and White introduced an initiation of motion parameter A which they expressed as a function of the dimensionless grain size, D_{gr}. Using primarily transport data collected by White and Day (1982) at the Wallingford Research Station (designated as HRS Series A) in a wide flume with a broadly graded sample a similar initiation of motion parameter A' has been determined. The A' values are the best A values based on the actual White and Day measured sediment concentrations followed by back calculations for A using the Ackers-White equations. These curves are plotted in Figure 1 along with the White and Day data. The bed distribution of these data can be expressed by the gradation coefficient $\sigma = (d_{84}/d_{16})^{1/2} = 4.198$. The original Ackers and White data are considered to work best for a single sediment size; thus the A versus D_{gr} curve is associated with a value $\sigma = 1$. For values of $D_{gr} < 56$, A' is greater than A, reflecting a "hiding factor" similar to that of Einstein and thereby reducing the transport of the finer sizes. When $D_{gr} > 56$, A' is less than A, resulting in an "exposure factor" for the larger sizes and resulting in increased transport.

The proposed procedure uses the σ value of a given bed distribution as an interpolating factor to get a best A'' from Figure 1, for each size of bed material, and hence of D_{gr}. For each grain size the best A'' is calculated as follows: If $1 < \sigma < 4.198$, then A'' is interpolated from the respective values of A and A', based on the given D_{gr}. If $\sigma = 1$, then $A'' = A$, if $\sigma = 4.198$, then $A'' = A'$. If $\sigma > 4.198$, then A'' is extrapolated based on the respective values of A and A'. Thus an A'' is determined for each sediment size. Once this is accomplished, the transport of each size is calculated according to the conventional Ackers-White procedure. The individual transport is then adjusted by the p_i factor to reflect the actual per cent of that size found in the bed.

A second procedure, to be referred to as the Heng procedure, involved the use of two graduation coefficients, σ_1 and σ_2, defined by $\sigma_1 = d_{50}/d_{16}$ and $\sigma_2 = d_{94}/d_{50}$. These were used as interpolation factors in the same way as σ above. They were used to reflect the bimodal nature of many bed distributions and in tests of river data, did a slightly better job than the Prasuhn Procedure. However, this procedure raised additional problems when incorporated into HEC-6 and further, was difficult to justify theoretically. Therefore, although the Heng procedure will be included in many of the figures, it will not be recommended nor discussed further.

5 Verification of the Prasuhn Procedure

Verification of the modified Ackers-White procedure has been reported previously (Prasuhn, Lewandowski, and Bagherzadeh 1987; Heng 1989; and Prasuhn and Heng 1990). Additional results have been included here for selected flume and river data. The concentrations shown in Figures 2-45 represent either the concentration by size fractions or the concentration of the total bed material load as indicated. There is clearly a variation in the accuracy of the results, but they are generally quite acceptable and are as good as can be achieved by other transport functions. As a general comment the overestimation of the very fine sand and the tendency for gravel sizes to increase as the particle size increases, major points that will be considered in detail later, are not obvious here.

Figures 2-14 represent selected Wallingford HRS Series A data (White and Day, 1982). Since the A'' curve was based on these data, it does not represent a true verification. Figure 2 is the total concentration for each run and the remaining figures are by size fractions. On these figures, and those that follow, the L-B results can be ignored as representing early work. The A&W data refer to the original Ackers-White procedure, and the Proposed refers to the Heng procedure. Sediment sizes ranged from 0.063, the beginning of size fraction 1, up to 15.7 mm, the end of size fraction 8. Those results labeled either Prasuhn or A&W will usually be of the greatest interest. Some of the lower numbered runs refer to very low discharges, but generally a selection of both good and poor results will be included. Note that each pair of figures refers to a specific run, in one case referencing the calculated to the measured data by a line of perfect agreement, and in the other comparing the calculated to the measured data on a size by size basis. The dashed lines in the first case give the range of variation within a factor of two. The size by size comparison is a much tougher comparison since it is on an arithmetic plot.

Figures 15-20 represent selected HRS Series B (White and Day, 1982) results for which the sediment sizes ranged from 0.063 to 6.35 mm. These data were not utilized in the developmental process. Figure 15 is once again the total concentration, but based on the calculation by size fractions, except for the original Ackers-White procedure (A&W). Note that the original Ackers-White procedure overestimated the sediment transport in both cases.

The remainder of the figures are for transport by size fractions, however, all of the runs are combined in Figure 16 which pertains to just the Prasuhn procedure. In some cases there is considerable deviation from the measured data, but not in any consistent fashion.

The remaining flume data which will be considered here were the data sets collected at the St. Anthony Falls Laboratory and reported by Hubbel et al. (1987). The generally coarse material was distributed from 0.5 up to 32 mm. These results, all based on the individual size fractions, are given in Figures 21-32. These would appear to give an excellent verification based on independent flume data.

Figures 33-42 are based on sand and gravel data from the Platte River (Kircher 1983). With the exception of the first figure, all results are shown by size fractions on arithmetic plots. Both the Prasuhn procedure and the original Ackers-White procedure give fair results.

Total concentration results are given for two sites on the Rio Grande River in Figures 43 and 44. Although the bed material was mostly medium to coarse sand, the sediment ranged from very fine sand to medium gravel (Nordin 1964).

The final river shown (Figure 45) is the Snake River data (Jones and Sietz 1980). Since the measured sediment sizes ranged up to 181 mm, it is unfortunate that this is one of the poorer sets of total concentration results. As it turns out, the original Ackers-White procedure gives the best results which is inconsistent with our usual observation concerning the application of the Ackers-White procedure for broadly graded sediments.

6 Incorporation of the Prasuhn Procedure into HEC-6

Problems with Incorporation

The original process of incorporating the modified Ackers-White procedure into HEC-6 involved little more than setting up a separate subroutine which was essentially parallel to the existing Ackers-White subroutine. However the incorporation of the above proposed procedure into HEC-6 created a number of problems which will be enumerated here.

The problems arose during either the coding or testing stages. They will be treated separately in no particular order below, although they *may be* interrelated. The resolution of the problems, or recommendations therefrom, will be considered as they occur as well as summarized at the end of the section.

a. The gradation coefficient, $\sigma = (d_{94}/d_{16})^{1/2}$ was used to express the spread of the bed sediment distribution and as an interpolating and extrapolating parameter for the incipient motion parameter A''. Previously only sand and larger sizes were considered, whereas in HEC-6 significant quantities of silt and clay are frequently encountered. It was not reasonable to include the clay and silt sizes in the computation of σ, so for purposes of this computation only, the bed was proportionally recomposed to include only the sand and larger sizes. This can not be fully justified on the basis of hiding and exposure factors, but no alternative could be found. It does not appear to be a serious problem.

b. In the computation of σ within HEC-6, evolving bed distributions, which may not always have been reasonable, led to values of σ well beyond what had been previously experienced or tested. (The HRS Series A data has a value $\sigma = 4.198$.) It was felt that this was unrealistic and σ was set equal to 6 when values of σ exceeded 6. This again seemed to work well, but the value of 6 was somewhat arbitrary.

c. During the testing with HEC-6 it was concluded that the hiding and exposure effects could not be pronounced when only sand sizes were present so the modification procedure for A' was bypassed when $D_{gr} <$ 50 for all sizes. This increased the very find sand transport, making more apparent the concerns relative to the overestimation of the finer material by the Ackers-White procedure. This apparent problem will be discussed further, below.

d. Some considerable evidence is now available concerning the overestimation of the fine sediments by the original Ackers-White procedure. In comparisons based on the HEC-6 test runs, both the original Ackers-White procedure and the modified Ackers-White procedure tended to overestimate the transport of the finer material and very fine sand in particular. It has been concluded that this is a valid criticism of the basic Ackers-White procedure requiring additional analysis. It is suggested that the best remedy lies in the adjustment of the exponent m. The rationale and method of adjustment is discussed along with the coefficient C, below.

e. A second problem coming out of the original Ackers-White procedure is the behavior of the coarser material, primarily gravel and larger sizes. This may have escaped notice previously because the transport was usually limited to only the smaller gravel sizes. However, if the transport is normalized so that each size is considered to cover 100% of the bed, transport will increase as the sediment size increases.

The problem which is presented in paragraph *e* is demonstrated in Figure 46 where a Froude number range from 0.3 to 1.2 is considered. (The effect becomes much more pronounced at still higher Froude numbers.) A hypothetical discharge, and width were picked for a wide rectangular channel. The required depth was then calculated to match the selected Froude numbers. Finally, the slope was determined so as to satisfy the Manning equation at constant Manning n. The calculations for sediment transport concentration are based on the assumption that each sediment size (very fine sand up to large cobbles) completely covers the bed.

Except for the smaller Froude numbers, there is a reversal of the curve for sediment sizes in excess of D_{gr} equal to approximately 60. Beyond this point, the sediment transport increases as the sediment size and D_{gr} increase. This, of course, is entirely unrealistic. The effect is more pronounced for $Fr > 0.8$ (the recommended upper limit of validity as recommended by Ackers and White).

Here, there is little to go on except the illogical behavior of the current Ackers-White procedure with regard to the larger sizes. One possible fix for this problem is to replace the existing functions for C with alternative equations. The proposed changes to C will also be discussed below.

Adjustments to *m* and *C*

It has been established that there are problems with both the Ackers-White procedure and the modifications thereto. The recommended adjustment for *m* is to replace the existing functions with an alternative expression which reduces the magnitude of *m* for very fine sand and, to a lesser degree, fine sand without affecting its magnitude for the larger sediments. The following set of equations were tested at the U.S. Army Engineer Waterways Experiment (WES) to determine a best equation:

$$m = 8.419/D_{gr}^{0.9} + 1.289 \qquad (14a)$$

$$m = 8.027/D_{gr}^{0.9} + 1.298 \qquad (14b)$$

$$m = 7.635/D_{gr}^{0.9} + 1.308 \qquad (14c)$$

$$m = 7.244/D_{gr}^{0.9} + 1.318 \qquad (14d)$$

$$m = 6.852/D_{gr}^{0.9} + 1.328 \qquad (14e)$$

These equations all achieve the goal of reducing the transport of the finer sediments without materially affecting the transport of the larger sizes. Equation 14e has the most effect. In each case the exponent of 0.9 was chosen to minimize the effect on the larger sizes.

Typical values of *m* for the original equation (Equation 6) as well as Equations 14a-e are given for various values of D_{gr} in Table 1.

The coefficient *C* was likewise to be tested by a set of equations. For D_{gr} values up to 166.7, the original equation (Equation 5) was used, but now extended over the greater range.

$$\log C = 2.86 \log D_{gr} - (\log D_{gr})^2 - 3.53 \qquad (5)$$

Above D_{gr} = 166.7 the alternative equations were

$$C = 0.00772 \tag{15a}$$

$$C = 0.3166/D_{gr} + 0.00582 \tag{15b}$$

$$C = 0.6296/D_{gr} + 0.00394 \tag{15c}$$

$$C = 0.9426/D_{gr} + 0.00207 \tag{15d}$$

$$C = 1.235/D_{gr} + 0.000316 \tag{15e}$$

Typical values of C for $D_{gr} > 166.7$ based on Equations 15a-e are given for various values of D_{gr} in Table 2. Unfortunately, adequate time was not available at WES to satisfactorily test all of the above equations as originally intended. The test sets that were completed only involved the sand sizes so the range of equations for C was not assessed. The only tests that ran successfully were those pertaining to the HEC-6 Example 1 involving the Ozark Reservoir. Example 1 ran with most of the proposed equations for m, the original Ackers-White procedure (MTC = 7), Test Example 1 using the Toffaleti procedure (MTC = 1), and Test Example 3 which is identical to Test Example 1 except that the Laursen procedure (MTC = 3) is used for sediment transport. Regrettably, there was some confusion in these runs and results for only four of the five m equations survive.

The HEC-6 computer results are tabulated in Tables 3-9. Tables 3, 4, and 5 are the Toffaleti, Laursen, and original Ackers-White results, respectively. Each of the tables contains two parts reflecting runs of 1 and 64 days. The original Ackers-White procedure gives higher transport of the finer material as expected, by as much as a factor of 2. The very fine sand in the sediment outflow perhaps best demonstrates this tendency. The effect is reduced during the second time interval, but this involves the HEC-6 computations and iterations to a greater extent. Tables 6, 7, 8, and 9 refer to successive equations for m. The increased reduction in very fine sand is apparent in each table. Again the effect is reduced for the second time period. It is felt that the reduction afforded by Equation 14b (Table 7) gives the best results, and this becomes the recommended equation for m, although additional study is also recommended.

Although the tests run at WES did not provide any insight into the behavior of different equations for C on HEC-6 output, the equations had been tested to some extent previously. Equation 15e received the greatest attention, and on this somewhat limited basis Equation 15d is recommended at present. This is also subject to the recommendation that additional testing be undertaken.

The above changes must be reasonable and consistent with the original Ackers-White procedure. Refer to Figure 47, which is a copy of Ackers and White's Figure 3 (1973). Here the proposed changes to *m* and *C* have been added to the Ackers and White graphs, illustrating that the proposed changes are consistent with their original data. In addition, they must not contradict the soundness or logic of the original Ackers-White procedure. The first point was somewhat satisfied by testing. The second can be justified as follows, based on the development by Ackers and White (1973). The numerical values in the expressions for the parameters *A*, *n*, *m* and *C* were ultimately determined by regression analysis. They (Ackers and White) explain that the regression first led to the expression for *n* followed by the incipient motion parameter *A*. At this point, the expressions for *m* and *C* were determined. Since the proposed changes in *m* and *C* are in mutually exclusive ranges of D_{gr}, there should be no violation of the original logic, other than the changes in *m* and *C* themselves.

7 Conclusions and Recommendations

No matter which version or form of Ackers-White is used, the argument of the log function in the expression for the mobility number or factor (Equation 1) must remain greater than zero. This requires that $y/d_s > 0.1$. This should be included in any code involving Ackers-White. For example, in the present subroutine ACKER, the following IF statement should be added shortly after statement 131 and immediately after the comment line "FGR = SEDIMENT MOBILITY FACTOR":

```
IF (EFD LE 0 · 1*SD(I))THEN
    FGR=0
    GOTO (the write statement immediately ahead of existing statement
    number statement 141)
ENDIF
```

Subsequently, under the above conditions, the calculation for GP(I) needs to be bypassed so that GP(I) will remain at the initialized value, SPV. (A standard fix up in the existing log function may already accomplish the same goal, but if it does not, this should avoid problems.)

The expansion of the code to cover 15 sand and larger sediment sizes is in operational order. It should be useful for at least cobble bed streams and will increase the range of HEC-6 when incorporated into the program.

Most important are the conclusions and recommendations concerning the Ackers-White procedure. It is still felt that there is some significant gain in the modified procedure as developed at South Dakota State University. However, it is now felt that the improvements are strictly valid only when the bed distribution is broadly graded. It may still be desirable to incorporate the program into HEC-6 under these conditions. Although reasonably verified against a broad range of river data, this study does not demonstrate a significantly improved function when tested in HEC-6. The testing did identify problems and point the way to simple, yet direct, improvements to the Ackers-White procedure. By replacing the functions for *m* and *C* in the original Ackers-White procedure, much of the criticism of the procedure is eliminated. It is recommended that the existing subroutine ACKER be used in HEC-6 with the changes made to the equations for m and C as given in Equations 14b and 15d. If the modified procedure using the bed coefficient S is still of interest to WES, that code can be provided.

By the end of this study the direction of work had changed abruptly, but for the better. The end product is simpler than envisioned at the start, but the recommended changes are significant. Time was not available at the end to fully evaluate these changes. Consequently, while the changes will improve the performance of the subroutine ACKER in HEC-6, they may not yet be optimized. It is recommended that the equations for m and C be tested further.

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Table 1
Values of m versus D_{gr} for Equation 14

Eq. number	D_{gr}					
	1	2	10	20	40	60
δ	11.00	6.17	2.31	1.82	1.58	1.50
14a	9.71	5.80	2.35	1.86	1.59	1.50
14b	9.33	5.60	2.31	1.84	1.59	1.50
14c	8.94	5.40	2.27	1.82	1.58	1.50
14d	8.56	5.20	2.23	1.81	1.58	1.50
14e	8.18	5.00	2.19	1.79	1.58	1.50

Table 2
Values of C versus D_{gr} for Equation 15

Eq. number	166.7	500	1000	2000	4000
15a	0.00772	0.00772	0.00772	0.00772	0.00772
15b	0.00772	0.00645	0.00614	0.00598	0.00590
15c	0.00772	0.00520	0.00457	0.00425	0.00410
15d	0.00772	0.00396	0.00301	0.00254	0.00231
15e	0.00772	0.00279	0.00155	0.00093	0.00062

Table 3
Calculated Sedimentation Results Using Toffaleti Method (MTC = 1)

TIME DAYS	ENTRY POINT	CLAY INFLOW	CLAY OUTFLOW	CLAY TRAP EFF	SILT INFLOW	SILT OUTFLOW	SILT TRAP EFF	SAND INFLOW	SAND OUTFLOW	SAND TRAP EFF
1.00	346.250	112.42			53.09			11.74		
	329.000	0.02			0.00			0.00		
	313.000	0.00			4.03			0.14		
TOTAL=	308.750	112.45	112.45	0.00	57.17	57.17	0.00	11.88	8.72	0.27

TABLE 5b-1. TOTAL AND LOAD BY SIZE CLASS IN TONS/DAY

	TOTAL	VF	F	M	C	VC
SEDIMENT INFLOW, (TONS/DAY)						
CLAY=	73455.01					
SILT=	75163.77	75163.77				
SAND AND/OR GRAVEL=	23781.49	3719.44	14075.24	4907.01	1079.80	
TOTAL LOAD	172401.28					
SEDIMENT OUTFLOW, (TONS/DAY)						
CLAY=	73473.77					
SILT=	80939.08	80939.08				
SAND AND/OR GRAVEL=	17658.16	5559.91	11108.59	955.27	34.38	
TOTAL LOAD	172073.00					

SECTION ID NO	BED CHANGE FEET	WS ELEV FEET	THALWEG EL FEET	Q CFS	SEDIMENT LOAD IN TONS/DAY CLAY	SILT	SAND
346.250	0.02	378.67	362.02	48000.	73456.	75164.	14518.
342.400	-0.01	376.18	352.95	48900.	73456.	75164.	27614.
337.100	0.08	371.33	351.90	48800.	73456.	75164.	26111.
333.200	0.00	365.43	349.00	48800.	73436.	75164.	25940.
329.000	-0.01	362.25	342.95	49900.	73476.	75168.	35646.
322.700	0.00	355.67	340.00	49000.	73476.	75168.	34989.
318.600	0.30	352.20	332.00	50000.	73476.	80939.	29513.
308.750	0.31	346.50	321.01	50900.	73476.	80939.	17652.

(Continued)

Table 3 (Concluded)

```
BOUNDARY CONDITION DATA, CONTROL POINT NO.    1

                              ..EVENT NO.      2
WATER    DISCHARGE=  50000.00
         ELEVATION=   345.300
       TEMPERATURE=    65.000
FLOW DURATION(DAYS)  54.00
************************************************************************************************
  TIME              ENTRY *           CLAY                  *          SILT                  *          SAND                *
  DAYS              POINT *   INFLOW  OUTFLOW   TRAP EFF*   INFLOW   OUTFLOW  TRAP EFF*   INFLOW   OUTFLOW  TRAP EFF*
                          *                                 *                               *                               *
 65.00            346.290*   7307.38                        *  3451.05                      *   763.15                      *
                  323.000*      1.96                        *     0.21                      *     0.02                      *
                  318.600*      0.00                        *   264.96                      *     9.15                      *
        TOTAL=    309.750*   7309.33  7309.34      0.00*   3716.22   3716.21     0.00*   772.32   474.93     0.39*
                          *                                 *                               *                               *
************************************************************************************************

TABLE SB-1.                       TOTAL    AND    LOAD BY SIZE CLASS IN TONS/DAY
                                                    VF          F           M           C          VC
SEDIMENT INFLOW, (TONS/DAY)
                          CLAY=       73456.01
                          SILT=       75163.77     75163.77
           SAND AND/OR GRAVEL=        23761.49      3719.44    14075.24     4907.01     1073.80
                                    ------------
                     TOTAL LOAD     172401.28

SEDIMENT OUTFLOW, (TONS/DAY)
                          CLAY=       73475.77
                          SILT=       80939.08     80939.08
           SAND AND/OR GRAVEL=        14755.22      3902.86     9305.00     1400.07       67.29
                                    ------------
                     TOTAL LOAD     169170.06


  SECTION   BED CHANGE    WS ELEV   THALWEG         Q       SEDIMENT LOAD IN TONS/DAY
   ID NO       FEET         FEET    EL FEET        CFS        CLAY      SILT      SAND
   346.290      1.19       378.55    343.19      48900.     73456.    75164.    14932.
   342.400     -0.34       376.17    352.96      48900.     73456.    75164.    15570.
   337.100      0.31       371.35    354.01      48900.     73436.    75164.    15192.
   333.200      0.30       365.43    345.00      48300.     73456.    75164.    15152.
   329.000     -0.14       362.24    342.38      45300.     73476.    75163.    17633.
   322.700     -0.25       355.53    339.71      49900.     73476.    75163.    23730.
   318.500      0.05       352.29    322.05      50300.     73476.    80939.    22729.
   309.750      0.35       345.50    321.39      50300.     73476.    80939.    14755.

      0  DATA ERRORS DETECTED.
```

Table 4
Calculated Sedimentation Results Using the Laursen Method (MTC = 3)

BOUNDARY CONDITION DATA, CONTROL POINT NO. 1

..EVENT NO. 1

WATER DISCHARGE= 50000.00
ELEVATION= 346.509
TEMPERATURE= 63.300
FLOW DURATION(DAYS) 1.000

TIME DAYS	ENTRY POINT	CLAY INFLOW	CLAY OUTFLOW	CLAY TRAP EFF	SILT INFLOW	SILT OUTFLOW	SILT TRAP EFF	SAND INFLOW	SAND OUTFLOW	SAND TRAP EFF
1.00	346.290	112.42			53.09			11.74		
	329.080	0.03			0.00			0.00		
	318.460	0.00			4.08			0.14		
TOTAL=	308.750	112.45	112.45	0.00	57.17	57.17	0.000	11.88	7.80	0.34

TABLE SB-1. TOTAL AND LOAD BY SIZE CLASS IN TONS/DAY

	TOTAL	VF	F	M	C	VC
SEDIMENT INFLOW, (TONS/DAY)						
CLAY=	73456.01					
SILT=	75163.77	75163.77				
SAND AND/OR GRAVEL=	23781.49	3719.44	14075.24	4907.01	1079.80	
TOTAL LOAD	172401.28					
SEDIMENT OUTFLOW, (TONS/DAY)						
CLAY=	73475.77					
SILT=	80939.08	80939.08				
SAND AND/OR GRAVEL=	15970.26	6471.70	9432.13	66.43	0.00	
TOTAL LOAD	170385.11					

SECTION ID NO	BED CHANGE FEET	WS ELEV FEET	THALWEG EL FEET	Q CFS	SEDIMENT LOAD IN TONS/DAY CLAY	SILT	SAND
346.290	0.00	378.67	362.00	48300.	73456.	75164.	23703.
342.480	0.01	376.13	353.01	48800.	73436.	75164.	17868.
337.180	0.00	371.33	354.00	48800.	73436.	75164.	17856.
333.200	0.06	365.43	343.00	48900.	73436.	75164.	17814.
329.900	-0.01	362.25	341.99	49300.	73476.	75163.	29147.
322.700	-0.01	353.47	323.99	45000.	73476.	75163.	35981.
318.500	0.00	352.20	332.00	50000.	73476.	80939.	33856.
308.750	0.01	346.50	321.01	50300.	73476.	80939.	15970.

(Continued)

Table 4 (Concluded)

BOUNDARY CONDITION DATA, CONTROL POINT NO. 1

..EVENT NO. 2

WATER DISCHARGE= 30090.00
ELEVATION= 346.500
TEMPERATURE= 65.000
FLOW DURATION(DAYS) 64.00

TIME DAYS	ENTRY POINT	CLAY INFLOW	CLAY OUTFLOW	CLAY TRAP EFF	SILT INFLOW	SILT OUTFLOW	SILT TRAP EFF	SAND INFLOW	SAND OUTFLOW	SAND TRAP EFF
65.00	346.2900	7367.38			3451.05			763.15		
	329.0600	1.96			0.21			0.02		
	314.6600	0.00			264.96			9.15		
TOTAL=	303.7500	7303.33	7309.34	0.00	3716.22	3716.21	0.000	772.32	371.73	0.520

TABLE SD-1. TOTAL AND LOAD BY SIZE CLASS IN TONS/DAY

	TOTAL	VF	F	M	C	VC
SEDIMENT INFLOW, (TONS/DAY)						
CLAY=	73456.01					
SILT=	75163.77	75163.77				
SAND AND/OR GRAVEL=	23781.49	3719.44	14075.24	4907.01	1079.80	
TOTAL LOAD	172401.28					
SEDIMENT OUTFLOW, (TONS/DAY)						
CLAY=	73475.77					
SILT=	80939.08	80939.08				
SAND AND/OR GRAVEL=	11515.43	3685.00	7666.30	163.16	0.00	
TOTAL LOAD	165930.25					

SECTION ID NO	BED CHANGE FEET	WS ELEV FEET	THALWEG EL FEET	Q CFS	SEDIMENT LOAD IN TONS/DAY CLAY	SILT	SAND
346.29)	0.32	374.53	362.32	48900.	73456.	75164.	21353.
342.40)	0.41	375.16	357.41	48800.	73456.	75164.	14462.
337.10)	0.00	371.35	354.30	48800.	73456.	75164.	14462.
333.20)	0.00	363.43	343.90	48800.	73456.	75164.	14459.
327.00)	-0.14	362.14	341.36	49000.	73476.	75160.	16852.
322.70)	0.00	355.67	343.06	49000.	73476.	75168.	16039.
318.60)	0.02	352.21	332.92	50000.	73476.	80939.	16654.
308.75)	0.24	344.50	321.26	56000.	73476.	80939.	11515.

0' DATA ERRORS DETECTED.

Table 5
Calculated Sedimentation Results Using the Original Ackers-White Method (MTC = 7)

```
BOUNDARY CONDITION DATA, CONTROL POINT NO.       1
                           ..EVENT NO.           1

WATER     DISCHARGE=  50000.00
          ELEVATION=   346.500
        TEMPERATURE=    65.000
FLOW DURATION(DAYS)     1.0000
```

TIME DAYS	ENTRY POINT	CLAY INFLOW	CLAY OUTFLOW	CLAY TRAP EFF	SILT INFLOW	SILT OUTFLOW	SILT TRAP EFF	SAND INFLOW	SAND OUTFLOW	SAND TRAP EFF
1.00	346.2900	112.42			53.09			11.74		
	329.0600	0.03			0.00			0.00		
	318.6800	0.00			4.08			0.14		
TOTAL=	308.7500	112.45	112.45	0.000	57.17	57.17	0.000	11.88	11.57	0.026

TABLE SD-1. TOTAL AND LOAD BY SIZE CLASS IN TONS/DAY FINEST TO COARSEST PARTICLE SIZES

	TOTAL	LOAD BY SIZE CLASS			
SEDIMENT INFLOW, (TONS/DAY)					
CLAY=	73456.00				
SILT=	75163.00	75163.00			
SAND AND/OR GRAVEL=	23781.49	3719.44	14075.24	4907.01	1079.80
TOTAL LOAD	172401.29				
SEDIMENT OUTFLOW, (TONS/DAY)					
CLAY=	73475.66				
SILT=	80939.24	80939.24			
SAND AND/OR GRAVEL=	23434.44	12852.56	9501.03	947.66	133.19
TOTAL LOAD	177849.33				

SECTION ID NO	BED CHANGE FEET	WS ELEV FEET	THALWEG EL FEET	Q CFS	SEDIMENT LOAD IN TONS/DAY CLAY	SILT	SAND
346.290	-0.02	378.64	361.98	48000.	73456.	75164.	34206.
342.400	0.01	376.16	353.01	48000.	73456.	75164.	18614.
337.100	0.00	371.35	354.00	48000.	73456.	75164.	18608.
333.200	0.00	365.44	345.00	48000.	73456.	75164.	18515.
329.060	-0.02	362.24	342.98	49000.	73476.	75168.	47011.
322.720	0.06	355.59	343.00	49000.	73476.	75168.	50796.
318.680	0.01	352.13	332.01	50000.	73476.	80939.	38999.
308.750	0.01	346.50	321.01	50000.	73476.	80939.	23434.

(Continued)

Table 5 (Concluded)

BOUNDARY CONDITION DATA, CONTROL POINT NO. 1
..EVENT NO. 2

WATER DISCHARGE= 50000.00
ELEVATION= 346.500
TEMPERATURE= 65.000
FLOW DURATION(DAYS) 64.0000

TIME DAYS	ENTRY POINT	CLAY INFLOW	CLAY OUTFLOW	CLAY TRAP EFF	SILT INFLOW	SILT OUTFLOW	SILT TRAP EFF	SAND INFLOW	SAND OUTFLOW	SAND TRAP EFF
65.00	346.2500	7307.38			3451.05			763.15		
	329.0000	1.96			0.21			0.02		
	318.6000	0.00			264.96			9.15		
TOTAL=	308.7500	7309.33	7309.33	0.000	3716.22	3716.22	0.000	772.32	466.16	0.400

TABLE SD-1. TOTAL AND LOAD BY SIZE CLASS IN TONS/DAY
FINEST TO COARSEST PARTICLE SIZES

SEDIMENT INFLOW, (TONS/DAY)

	TOTAL				
CLAY=	73456.00				
SILT=	75163.00	75163.00			
SAND AND/OR GRAVEL=	23781.49	3719.44	14075.24	4907.01	1079.80
TOTAL LOAD	172401.29				

SEDIMENT OUTFLOW, (TONS/DAY)

	TOTAL				
CLAY=	73475.66				
SILT=	80939.24	80939.24			
SAND AND/OR GRAVEL=	14387.27	4270.00	8519.96	1368.50	228.21
TOTAL LOAD	168802.16				

SECTION ID NO	BED CHANGE FEET	WS ELEV FEET	THALWEG EL FEET	Q CFS	SEDIMENT LOAD IN TONS/DAY CLAY	SILT	SAND
346.250	-0.03	378.60	341.97	48000.	73456.	75164.	23860.
342.400	0.41	376.12	338.41	48000.	73456.	75164.	17104.
337.100	0.00	371.30	334.06	48000.	73456.	75164.	17096.
333.200	0.00	365.42	345.06	48000.	73456.	75164.	17047.
329.000	-0.15	362.23	342.81	49000.	73476.	75168.	20111.
322.700	-0.02	355.63	339.97	49000.	73476.	75168.	20756.
318.600	-0.13	352.17	331.87	50000.	73476.	80939.	25113.
308.750	0.53	346.50	321.51	50000.	73476.	80939.	14387.

Table 6
Calculated Results Using the Modified Ackers-White Method, *m* from Equation 14a

BOUNDARY CONDITION DATA, CONTROL POINT NO. 1
..EVENT NO. 1

WATER DISCHARGE= 50000.00
ELEVATION= 346.500
TEMPERATURE= 65.000
FLOW DURATION(DAYS) 1.0000

TIME DAYS	ENTRY POINT	CLAY INFLOW	CLAY OUTFLOW	CLAY TRAP EFF	SILT INFLOW	SILT OUTFLOW	SILT TRAP EFF	SAND INFLOW	SAND OUTFLOW	SAND TRAP EFF
1.00	346.290	112.42			53.09			11.74		
	329.000	0.03			0.00			0.00		
	318.600	0.00			4.08			0.14		
TOTAL=	308.750	112.45	112.45	0.00	57.17	57.17	0.00	11.88	9.33	0.21

TABLE SD-1.

	TOTAL AND	LOAD BY SIZE CLASS IN TONS/DAY FINEST TO COARSEST PARTICLE SIZES			
SEDIMENT INFLOW, (TONS/DAY)					
CLAY=	73456.00				
SILT=	75163.80	75163.80			
SAND AND/OR GRAVEL=	23781.49	3719.44	14075.24	4907.01	1079.80
TOTAL LOAD	172401.29				
SEDIMENT OUTFLOW, (TONS/DAY)					
CLAY=	73475.66				
SILT=	80939.24	80939.24			
SAND AND/OR GRAVEL=	18906.45	8616.44	9175.90	984.93	129.18
TOTAL LOAD	173321.34				

SECTION ID NO	SED CHANGE FEET	WS ELEV FEET	THALWEG EL FEET	Q CFS	SEDIMENT LOAD IN TONS/DAY CLAY	SILT	SAND
346.290	-0.02	378.64	361.98	48800.	73456.	75164.	32602.
342.400	0.01	376.16	353.01	48800.	73456.	75164.	17668.
337.100	0.00	371.35	354.00	48800.	73456.	75164.	17662.
333.200	0.00	365.44	345.00	48800.	73456.	75164.	17568.
329.000	-0.02	362.24	342.98	49000.	73476.	75168.	42439.
322.700	0.00	355.59	340.00	49000.	73476.	75168.	45525.
318.600	0.01	352.13	332.01	50000.	73476.	80939.	34712.
308.750	0.01	346.50	321.01	50000.	73476.	80939.	18906.

(Continued)

Table 6 (Concluded)

BOUNDARY CONDITION DATA, CONTROL POINT NO. 1
..EVENT NO. 2

WATER DISCHARGE= 50000.00
ELEVATION= 346.500
TEMPERATURE= 65.000
FLOW DURATION(DAYS) 64.0000

TIME DAYS	ENTRY POINT	CLAY INFLOW	CLAY OUTFLOW	CLAY TRAP EFF	SILT INFLOW	SILT OUTFLOW	SILT TRAP EFF	SAND INFLOW	SAND OUTFLOW	SAND TRAP EFF
65.00	346.290	7307.38			3451.05			763.15		
	329.000	1.96			0.21			0.02		
	318.600	0.00			264.96			9.15		
TOTAL=	308.750	7309.33	7309.33	0.00	3716.22	3716.22	0.00	772.32	451.82	0.41

TABLE SB-1. TOTAL AND LOAD BY SIZE CLASS IN TONS/DAY
FINEST TO COARSEST PARTICLE SIZES

SEDIMENT INFLOW, (TONS/DAY)

	TOTAL				
CLAY=	73456.00				
SILT=	75163.80	75163.80			
SAND AND/OR GRAVEL=	23781.49	3719.44	14075.24	4907.01	1079.80
TOTAL LOAD	172401.29				

SEDIMENT OUTFLOW, (TONS/DAY)

	TOTAL				
CLAY=	73475.66				
SILT=	80939.24	80939.24			
SAND AND/OR GRAVEL=	14004.21	4247.07	8106.49	1426.53	224.11
TOTAL LOAD	168419.10				

SECTION ID NO	BED CHANGE FEET	WS ELEV FEET	THALWEG EL FEET	Q CFS	SEDIMENT LOAD IN TONS/DAY CLAY	SILT	SAND
346.290	-0.01	378.61	361.99	48800.	73456.	75164.	23748.
342.400	0.42	376.13	353.42	48800.	73456.	75164.	16901.
337.100	0.00	371.31	354.00	48800.	73456.	75164.	16893.
333.200	0.09	365.42	345.00	48800.	73456.	75164.	16843.
329.000	-0.16	362.24	342.84	49000.	73476.	75168.	19335.
322.700	-0.02	355.63	339.98	49000.	73476.	75168.	19654.
318.600	-0.18	352.17	331.82	50000.	73476.	80939.	25356.
308.750	0.56	346.50	321.56	50000.	73476.	80939.	14004.

Table 7
Calculated Results Using the Modified Ackers-White Method, *m* from Equation 14b

BOUNDARY CONDITION DATA, CONTROL POINT NO. 1
..EVENT NO. 1

WATER DISCHARGE= 50000.00
ELEVATION= 346.500
TEMPERATURE= 65.000
FLOW DURATION(DAYS) 1.0000

TIME DAYS	ENTRY POINT	CLAY INFLOW	CLAY OUTFLOW	CLAY TRAP EFF	SILT INFLOW	SILT OUTFLOW	SILT TRAP EFF	SAND INFLOW	SAND OUTFLOW	SAND TRAP EFF
1.00	346.2500	112.42			53.09			11.74		
	329.0000	0.03			0.00			0.00		
	310.6000	0.00			4.08			0.14		
TOTAL=	308.7500	112.45	112.45	0.000	57.17	57.17	0.000	11.88	8.03	0.320

TABLE SD-1. TOTAL AND LOAD BY SIZE CLASS IN TONS/DAY
FINEST TO COARSEST PARTICLE SIZES

SEDIMENT INFLOW, (TONS/DAY)

	TOTAL				
CLAY=	73456.00				
SILT=	75163.00	75163.00			
SAND AND/OR GRAVEL=	23781.49	3719.44	14075.24	4907.01	1079.80
TOTAL LOAD	172401.29				

SEDIMENT OUTFLOW, (TONS/DAY)

	TOTAL				
CLAY=	73475.64				
SILT=	80939.24	80939.24			
SAND AND/OR GRAVEL=	16261.20	7040.85	8056.96	1022.84	140.56
TOTAL LOAD	170676.10				

SECTION ID NO	BED CHANGE FEET	WS ELEV FEET	THALWEG EL FEET	Q CFS	SEDIMENT LOAD IN TONS/DAY CLAY	SILT	SAND
346.250	-0.01	378.64	361.99	48000.	73456.	75164.	30414.
342.400	0.01	376.16	359.01	48000.	73456.	75164.	16371.
337.100	0.00	371.35	354.00	48000.	73456.	75164.	16365.
333.200	0.00	365.44	345.00	48000.	73456.	75164.	16267.
329.000	-0.02	362.24	342.90	49000.	73476.	75160.	35520.
322.700	0.00	355.59	343.00	49000.	73476.	75160.	39539.
318.600	0.00	352.13	332.00	50000.	73476.	80939.	30507.
308.750	0.01	346.50	321.01	50000.	73476.	80939.	16261.

(Continued)

Table 7 (Concluded)

BOUNDARY CONDITION DATA, CONTROL POINT NO. 1
..EVENT NO. 2

WATER DISCHARGE= 50000.00
ELEVATION= 346.500
TEMPERATURE= 65.000
FLOW DURATION(DAYS) 64.0000

TIME DAYS	ENTRY POINT	CLAY INFLOW	CLAY OUTFLOW	CLAY TRAP EFF	SILT INFLOW	SILT OUTFLOW	SILT TRAP EFF	SAND INFLOW	SAND OUTFLOW	SAND TRAP EFF
65.00	346.290	7307.38			3451.05			763.15		
	329.000	1.96			0.21			0.02		
	318.600	0.00			264.96			9.15		
TOTAL=	308.750	7309.33	7309.33	0.00	3716.22	3716.22	0.000	772.32	410.42	0.46

TABLE SD-1. TOTAL AND LOAD BY SIZE CLASS IN TONS/DAY
FINEST TO COARSEST PARTICLE SIZES

SEDIMENT INFLOW, (TONS/DAY)

	TOTAL				
CLAY=	73456.80				
SILT=	75163.00	75163.00			
SAND AND/OR GRAVEL=	23781.49	3719.44	14075.24	4907.01	1079.80
TOTAL LOAD	172401.29				

SEDIMENT OUTFLOW, (TONS/DAY)

	TOTAL				
CLAY=	73475.64				
SILT=	80939.24	80939.24			
SAND AND/OR GRAVEL=	12988.51	4041.70	7344.92	1374.01	227.87
TOTAL LOAD	167403.40				

SECTION ID NO	BED CHANGE FEET	WS ELEV FEET	THALWEG EL FEET	Q CFS	SEDIMENT LOAD IN TONS/DAY CLAY	SILT	SAND
346.290	-0.01	378.61	361.99	48000.	73456.	75164.	23717.
342.400	0.47	376.13	353.47	48000.	73456.	75164.	16012.
337.100	0.00	371.31	354.08	48000.	73456.	75164.	16012.
333.200	0.06	365.43	345.08	48000.	73456.	75164.	15965.
329.000	-0.15	362.24	342.05	49000.	73476.	75168.	18489.
322.700	-0.01	355.63	339.95	49000.	73476.	75168.	18616.
318.600	-0.17	352.17	331.02	50000.	73476.	80939.	23851.
308.750	0.53	346.50	321.92	50000.	73476.	80939.	12989.

Table 8
Calculated Results Using the Modified Ackers-White Method, *m* from Equation 14c

```
BOUNDARY CONDITION DATA. CONTROL POINT NO.      1
                         ..EVENT NO.            1
WATER    DISCHARGE=  50000.00
         ELEVATION=   346.500
       TEMPERATURE=    65.000
FLOW DURATION(DAYS)    1.0000
```

TIME DAYS	ENTRY POINT	CLAY INFLOW	CLAY OUTFLOW	CLAY TRAP EFF	SILT INFLOW	SILT OUTFLOW	SILT TRAP EFF	SAND INFLOW	SAND OUTFLOW	SAND TRAP EFF
1.00	346.290	112.42			53.09			11.74		
	329.000	0.03			0.00			0.00		
	318.600	0.00			4.08			0.14		
TOTAL=	308.750	112.45	112.45	0.00	57.17	57.17	0.00	11.88	6.99	0.41

TABLE SD-1. TOTAL AND LOAD BY SIZE CLASS IN TONS/DAY
FINEST TO COARSEST PARTICLE SIZES

SEDIMENT INFLOW, (TONS/DAY)

	TOTAL				
CLAY=	73456.00				
SILT=	75163.80	75163.80			
SAND AND/OR GRAVEL=	23781.49	3719.44	14075.24	4907.01	1079.80
TOTAL LOAD	172401.29				

SEDIMENT OUTFLOW, (TONS/DAY)

	TOTAL				
CLAY=	73475.66				
SILT=	80939.24	80939.24			
SAND AND/OR GRAVEL=	14151.07	5923.12	7001.34	1071.23	155.38
TOTAL LOAD	168565.97				

SECTION ID NO	BED CHANGE FEET	WS ELEV FEET	THALWEG EL FEET	Q CFS	SEDIMENT LOAD IN TONS/DAY CLAY	SILT	SAND
346.290	-0.01	378.64	361.99	48800.	73456.	75164.	28608.
342.400	0.01	376.16	353.01	48800.	73456.	75164.	15316.
337.100	0.00	371.35	354.00	48800.	73456.	75164.	15310.
333.200	0.00	365.44	345.00	48800.	73456.	75164.	15210.
329.000	-0.01	362.24	342.99	49000.	73476.	75168.	30343.
322.700	0.00	355.59	340.00	49000.	73476.	75168.	34591.
318.600	0.00	352.13	332.00	50000.	73476.	80939.	27080.
308.750	0.01	346.50	321.01	50000.	73476.	80939.	14151.

(Continued)

Table 8 (Concluded)

BOUNDARY CONDITION DATA. CONTROL POINT NO. 1
..EVENT NO. 2

WATER DISCHARGE= 50000.00
ELEVATION= 346.500
TEMPERATURE= 65.000
FLOW DURATION(DAYS) 64.0000

TIME DAYS	ENTRY POINT	CLAY INFLOW	CLAY OUTFLOW	CLAY TRAP EFF	SILT INFLOW	SILT OUTFLOW	SILT TRAP EFF	SAND INFLOW	SAND OUTFLOW	SAND TRAP EFF
65.00	346.290	7307.38			3451.05			763.15		
	329.000	1.96			0.21			0.02		
	318.600	0.00			264.96			9.15		
TOTAL=	308.750	7309.33	7309.33	0.00	3716.22	3716.22	0.00	772.32	386.23	0.50

TABLE SD-1. TOTAL AND LOAD BY SIZE CLASS IN TONS/DAY
FINEST TO COARSEST PARTICLE SIZES

SEDIMENT INFLOW. (TONS/DAY)

	TOTAL				
CLAY=	73456.00				
SILT=	75163.88	75163.88			
SAND AND/OR GRAVEL=	23781.49	3719.44	14075.24	4907.01	1079.80
TOTAL LOAD	172401.29				

SEDIMENT OUTFLOW. (TONS/DAY)

	TOTAL				
CLAY=	73475.66				
SILT=	80939.24	80939.24			
SAND AND/OR GRAVEL=	12002.71	3836.33	6596.53	1333.17	236.68
TOTAL LOAD	166417.60				

SECTION ID NO	BED CHANGE FEET	WS ELEV FEET	THALWEG EL FEET	Q CFS	SEDIMENT LOAD IN TONS/DAY CLAY	SILT	SAND
346.290	0.00	378.62	362.00	48800.	73456.	75164.	23669.
342.400	0.52	376.14	353.52	48800.	73456.	75164.	15102.
337.100	0.00	371.32	354.00	48800.	73456.	75164.	15102.
333.200	0.00	365.43	345.00	48800.	73456.	75164.	15057.
329.000	-0.15	362.24	342.85	49000.	73476.	75168.	17519.
322.700	-0.01	355.63	339.99	49000.	73476.	75168.	17691.
318.600	-0.14	352.17	331.86	50000.	73476.	80939.	22230.
308.750	0.50	346.50	331.50	50000.	73476.	80939.	12003.

Table 9

Calculated Results Using the Modified Ackers-White Method, *m* from Equation 14d

BOUNDARY CONDITION DATA, CONTROL POINT NO. 1
..EVENT NO. 2

WATER	DISCHARGE=	50000.00
	ELEVATION=	346.500
	TEMPERATURE=	65.000
FLOW DURATION(DAYS)		64.0000

TIME DAYS	ENTRY POINT	CLAY INFLOW	CLAY OUTFLOW	CLAY TRAP EFF	SILT INFLOW	SILT OUTFLOW	SILT TRAP EFF	SAND INFLOW	SAND OUTFLOW	SAND TRAP EFF
65.00	346.290	7307.38			3451.05			763.15		
	329.000	1.96			0.21			0.02		
	318.600	0.00			264.96			9.15		
TOTAL=	308.750	7309.33	7309.33	0.00	3716.22	3716.22	0.00	772.32	360.23	0.53

TABLE SD-1. TOTAL AND LOAD BY SIZE CLASS IN TONS/DAY
FINEST TO COARSEST PARTICLE SIZES

	TOTAL				
SEDIMENT INFLOW, (TONS/DAY)					
CLAY=	73456.00				
SILT=	75163.80	75163.80			
SAND AND/OR GRAVEL=	23781.49	3719.44	14075.24	4907.01	1079.80
TOTAL LOAD	172401.29				
SEDIMENT OUTFLOW, (TONS/DAY)					
CLAY=	73475.66				
SILT=	80939.24	80939.24			
SAND AND/OR GRAVEL=	11198.65	3784.87	5866.39	1299.31	248.08
TOTAL LOAD	165613.54				

SECTION ID NO	BED CHANGE FEET	WS ELEV FEET	THALWEG EL FEET	Q CFS	SEDIMENT LOAD IN TONS/DAY CLAY	SILT	SAND
346.290	0.03	378.62	362.03	48800.	73456.	75164.	23539.
342.400	0.54	376.14	353.54	48800.	73456.	75164.	14561.
337.100	0.00	371.32	354.00	48800.	73456.	75164.	14561.
333.200	0.00	365.44	345.00	48800.	73456.	75164.	14518.
329.000	-0.14	362.25	342.86	49000.	73476.	75168.	16845.
322.700	-0.01	355.62	339.99	49000.	73476.	75168.	16950.
318.600	-0.12	352.17	331.88	50000.	73476.	80939.	20734.
308.750	0.47	346.50	321.47	50000.	73476.	80939.	11199.

(Continued)

Table 9 (Concluded)

BOUNDARY CONDITION DATA, CONTROL POINT NO. 1
..EVENT NO. 1

WATER DISCHARGE= 50000.00
ELEVATION= 346.500
TEMPERATURE= 65.000
FLOW DURATION(DAYS) 1.0000

TIME DAYS	ENTRY POINT	CLAY INFLOW	CLAY OUTFLOW	CLAY TRAP EFF	SILT INFLOW	SILT OUTFLOW	SILT TRAP EFF	SAND INFLOW	SAND OUTFLOW	SAND TRAP EFF
1.00	346.290	112.42			53.09			11.74		
	329.000	0.03			0.00			0.00		
	318.600	0.00			4.08			0.14		
TOTAL=	308.750	112.45	112.45	0.00	57.17	57.17	0.00	11.88	6.40	0.46

TABLE SD-1. TOTAL AND LOAD BY SIZE CLASS IN TONS/DAY
FINEST TO COARSEST PARTICLE SIZES

	TOTAL	LOAD BY SIZE CLASS			
SEDIMENT INFLOW, (TONS/DAY)					
CLAY=	73456.00				
SILT=	75163.80	75163.80			
SAND AND/OR GRAVEL=	23781.49	3719.44	14075.24	4907.01	1079.80
TOTAL LOAD	172401.29				
SEDIMENT OUTFLOW, (TONS/DAY)					
CLAY=	73475.66				
SILT=	80939.24	80939.24			
SAND AND/OR GRAVEL=	12954.42	5681.33	5992.45	1108.01	172.64
TOTAL LOAD	167369.32				

SECTION ID NO	BED CHANGE FEET	WS ELEV FEET	THALWEG EL FEET	Q CFS	SEDIMENT LOAD IN TONS/DAY CLAY	SILT	SAND
346.290	-0.01	378.64	341.99	48800.	73456.	75164.	27101.
342.400	0.01	376.16	353.01	48800.	73456.	75164.	14239.
337.100	0.00	371.35	354.00	48800.	73456.	75164.	14233.
333.200	0.00	365.44	345.00	48800.	73456.	75164.	14131.
329.000	-0.01	362.24	342.99	49000.	73476.	75168.	27216.
322.700	0.00	355.59	340.00	49000.	73476.	75168.	31146.
318.600	0.00	352.13	332.00	50000.	73476.	80939.	24699.
308.750	0.01	346.50	321.01	50000.	73476.	80939.	12954.

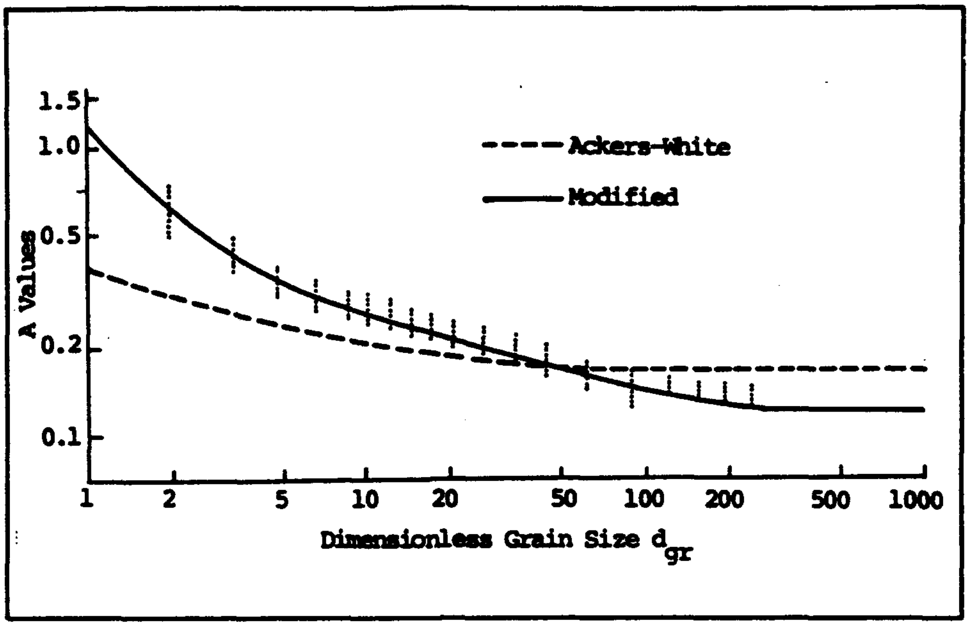

Figure 1. Curve for A vs d_{gr}

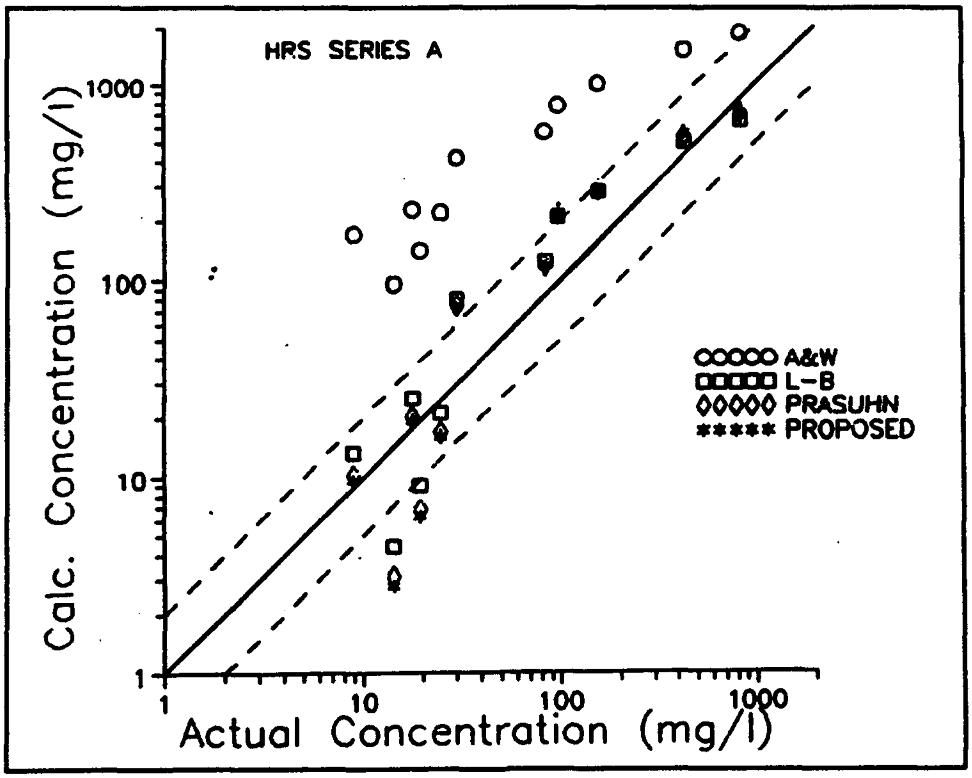

Figure 2. HRS Series A, Total Concentrations

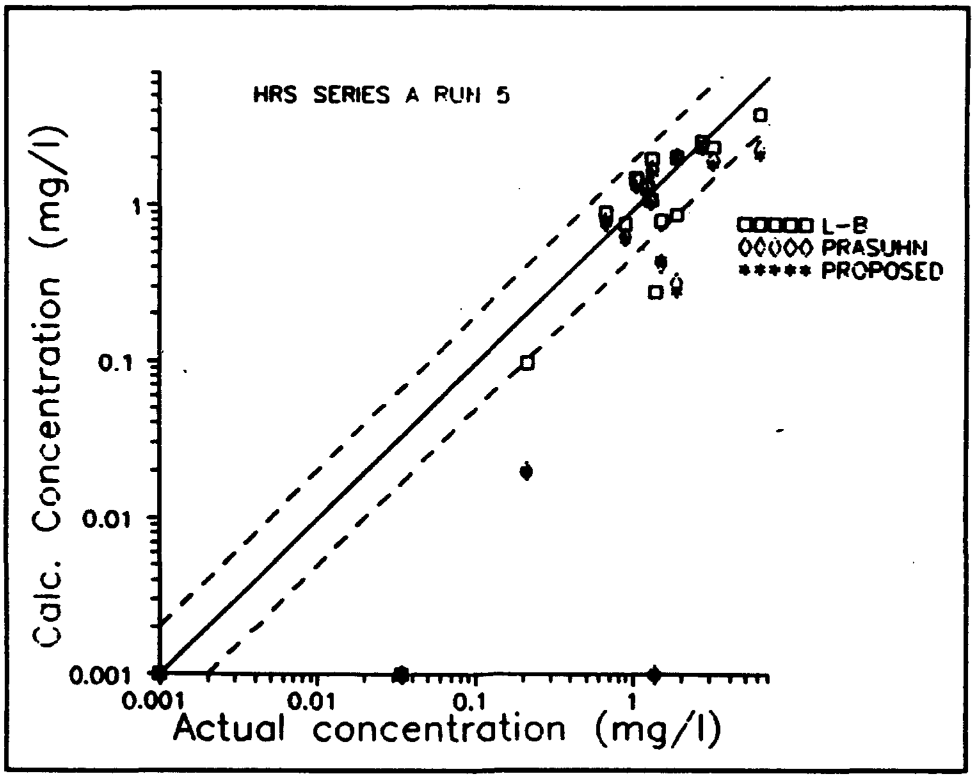

Figure 3. HRS Series A, Run 5, Concentration by Size Fractions

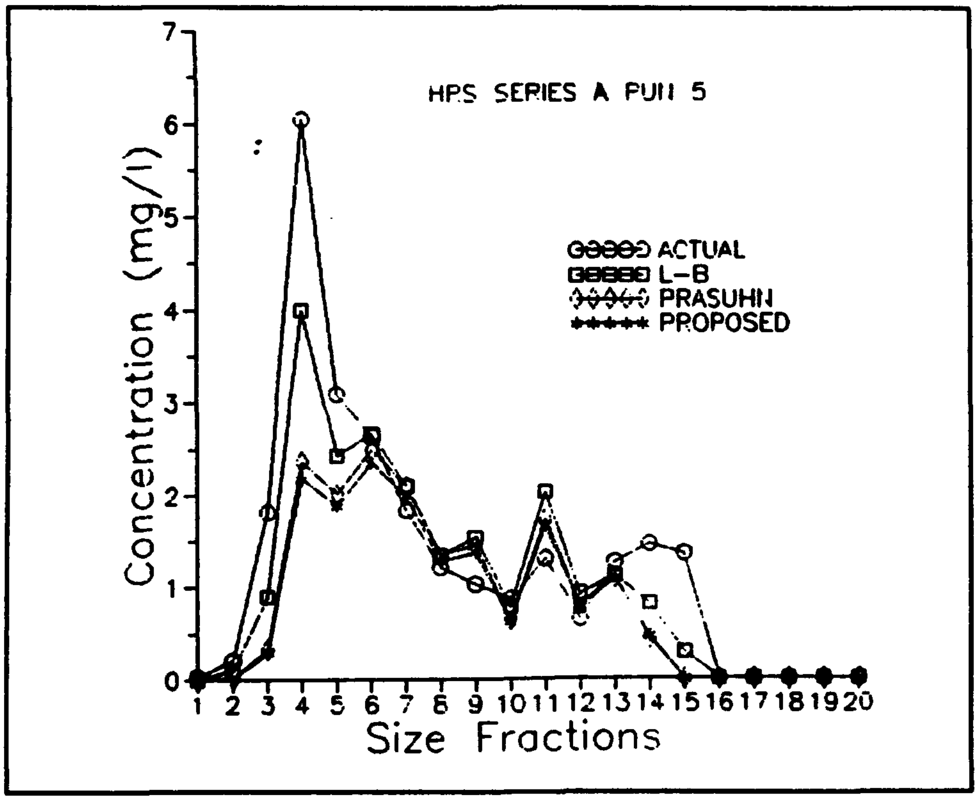

Figure 4. HRS Series A, Run 5, Concentration by Size Fractions

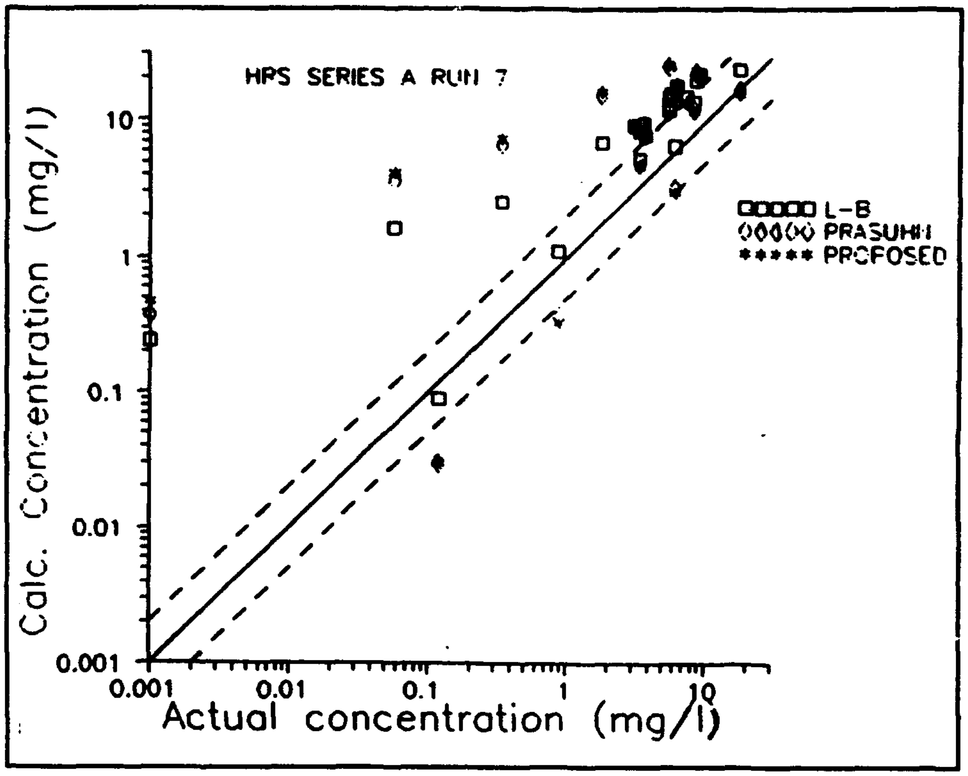

Figure 5. HRS Series A, Run 7, Concentration by Size Fractions

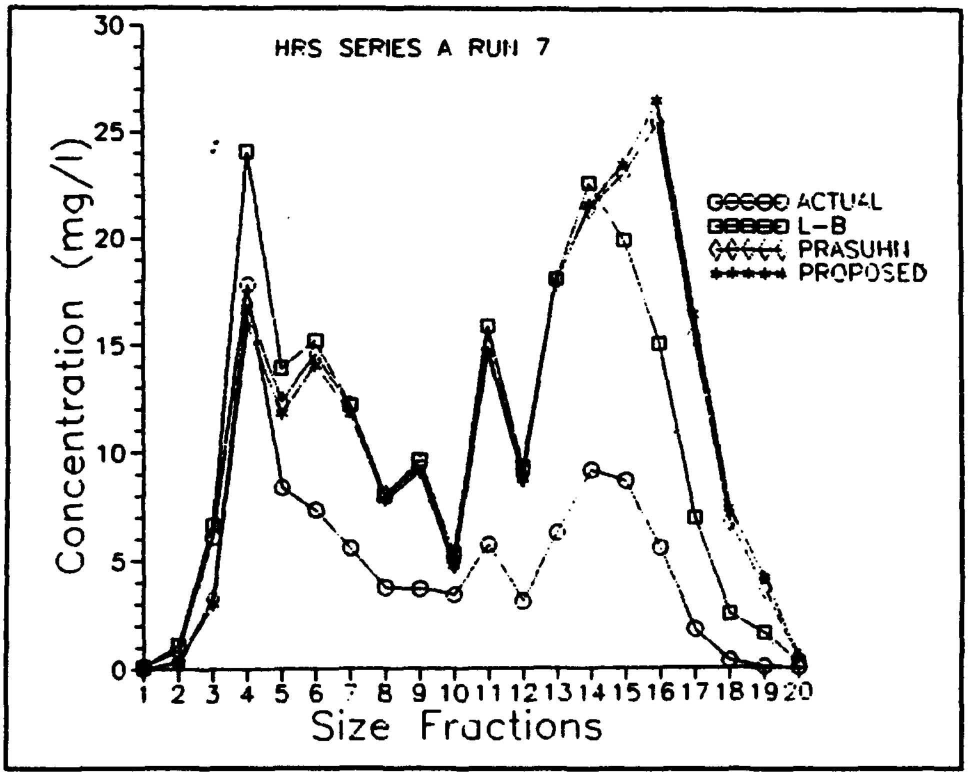

Figure 6. HRS Series A, Run 7, Concentration by Size Fractions

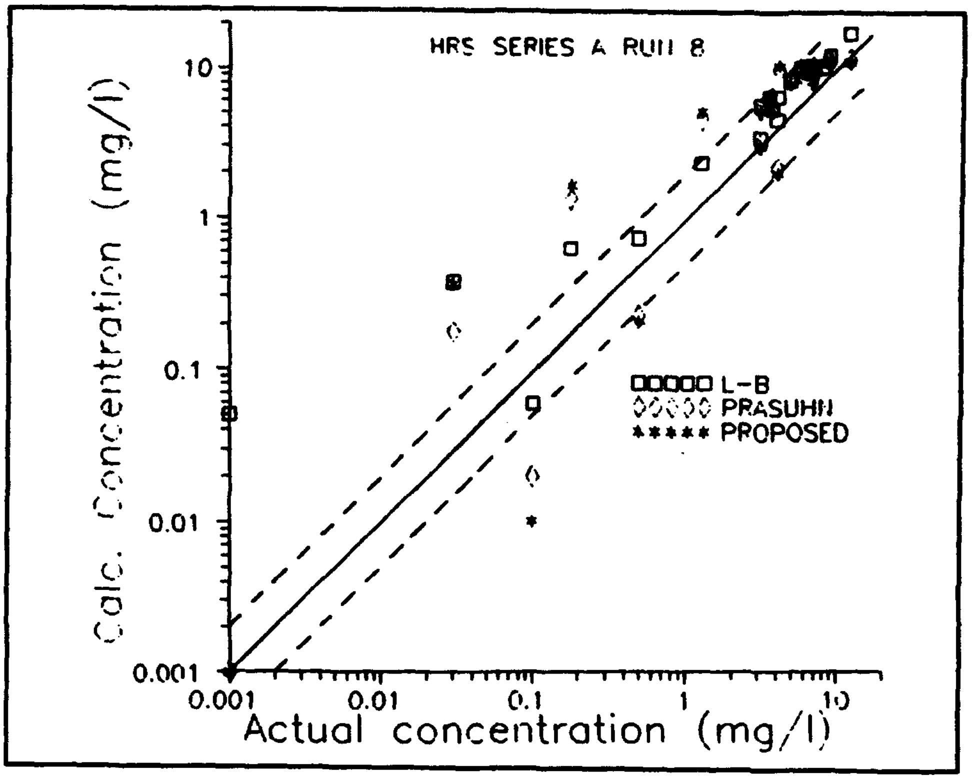

Figure 7. HRS Series A, Run 8, Concentration by Size Fractions

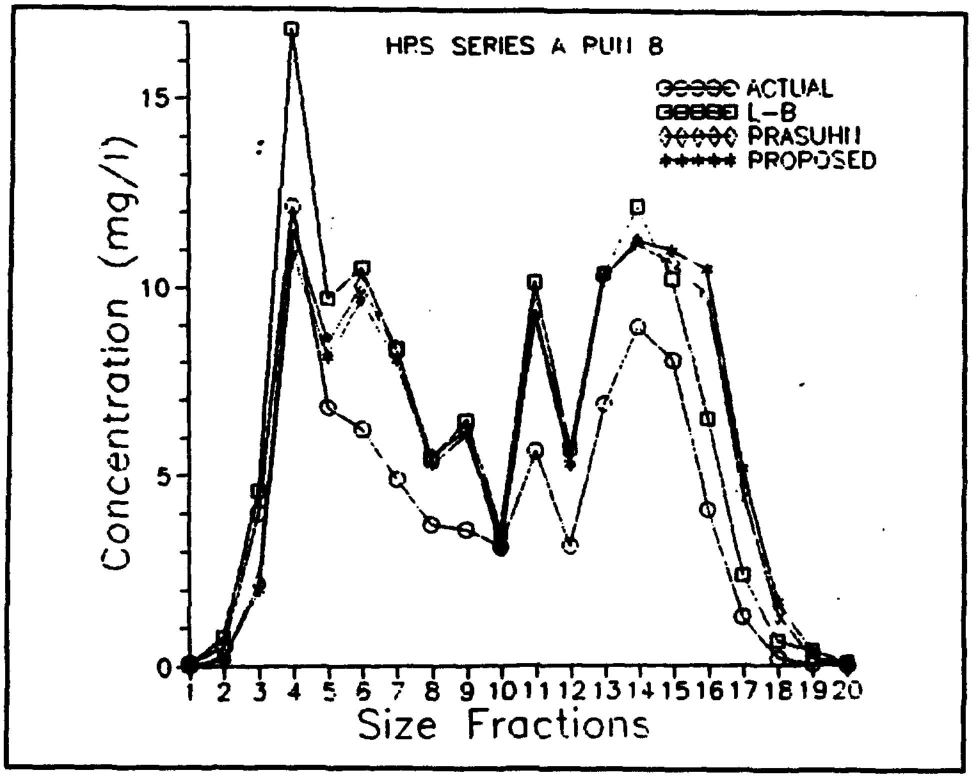

Figure 8. HRS Series A, Run 8, Concentration by Size Fractions

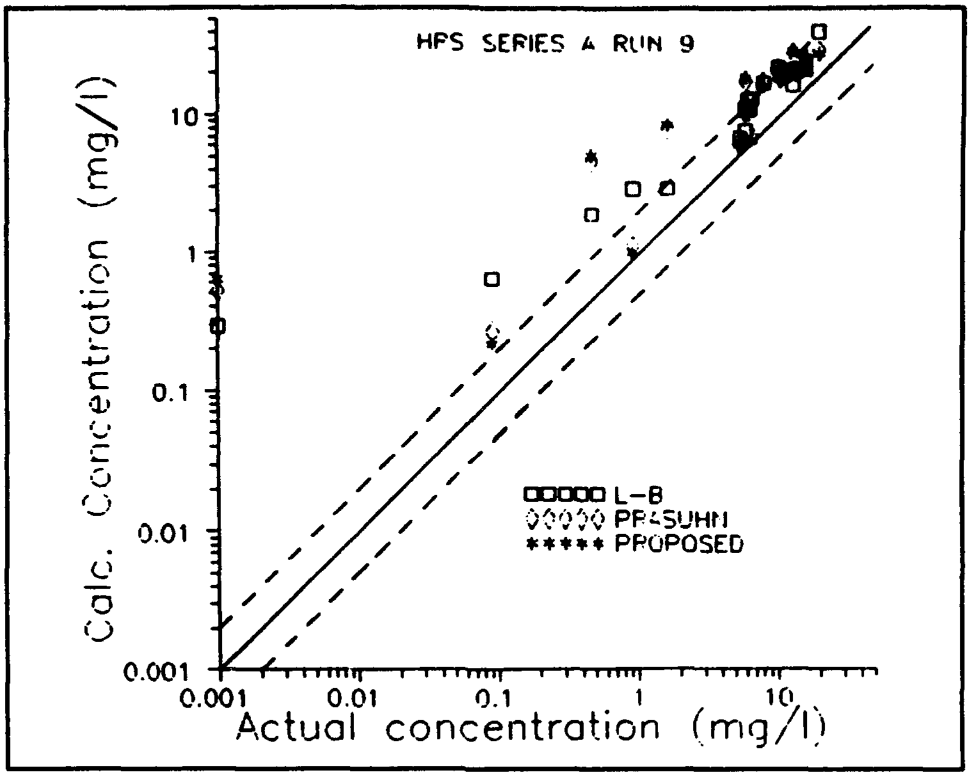

Figure 9. HRS Series A, Run 9, Concentration by Size Fractions

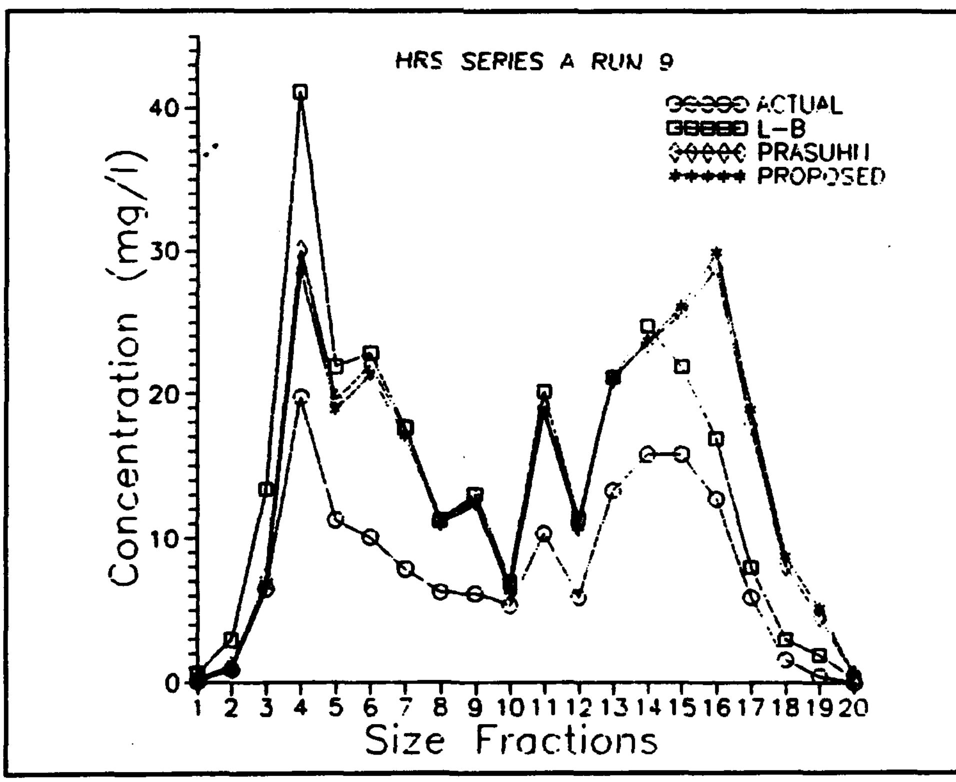

Figure 10. HRS Series A, Run 9, Concentration by Size Fractions

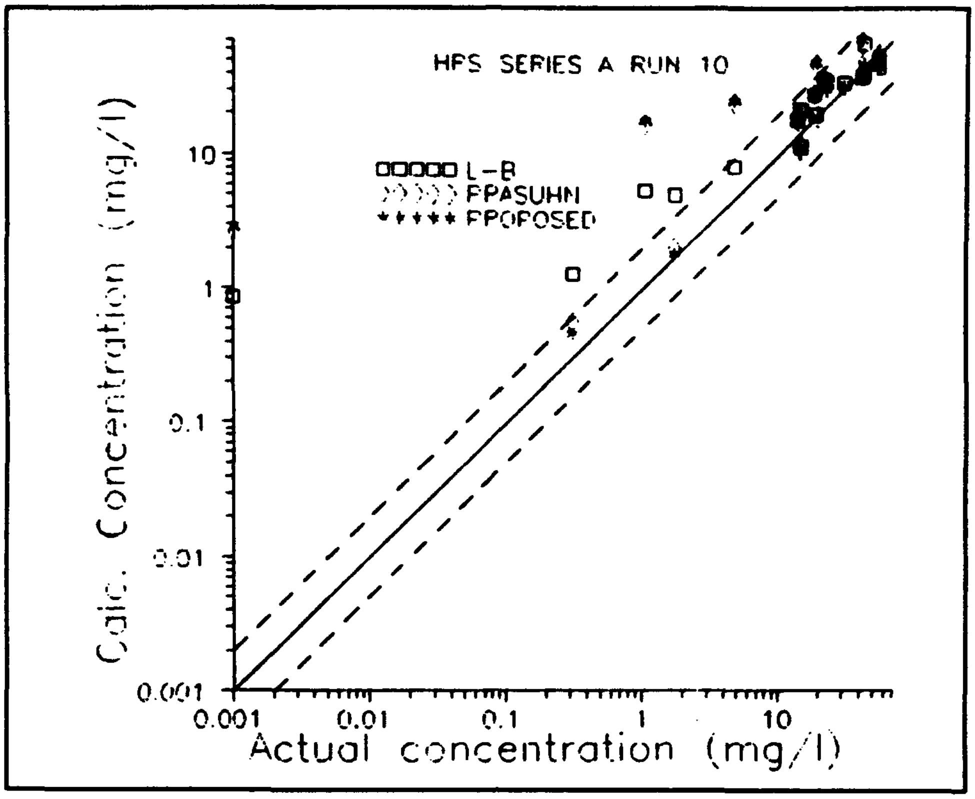

Figure 11. HRS Series A, Run 10, Concentration by Size Fractions

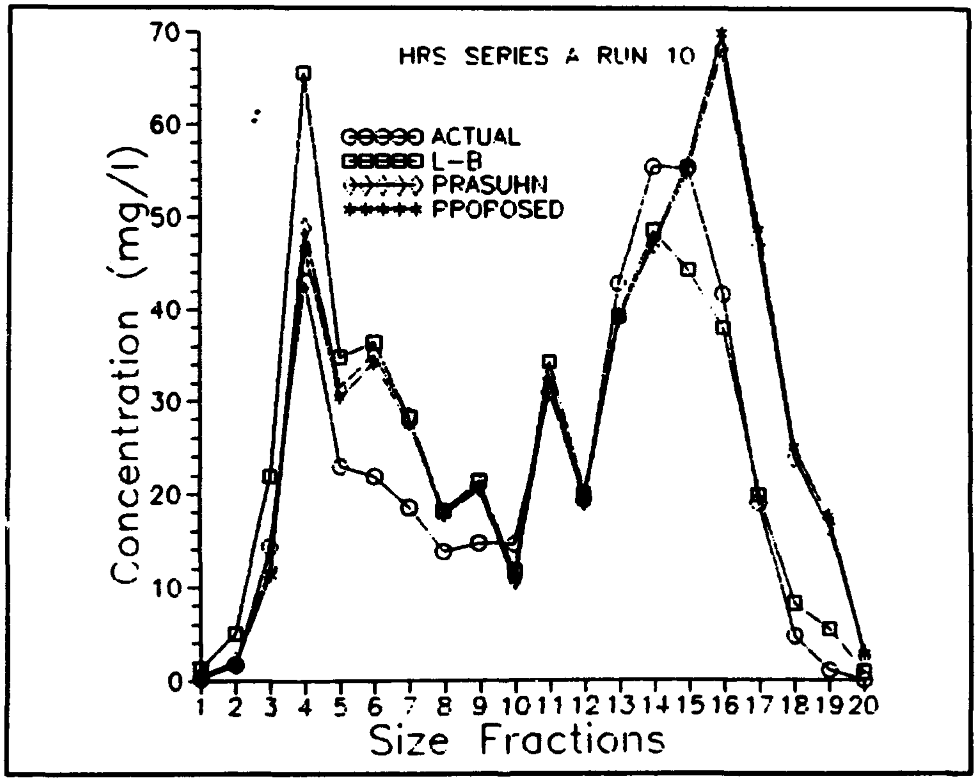

Figure 12. HRS Series A, Run 10, Concentration by Size Fractions

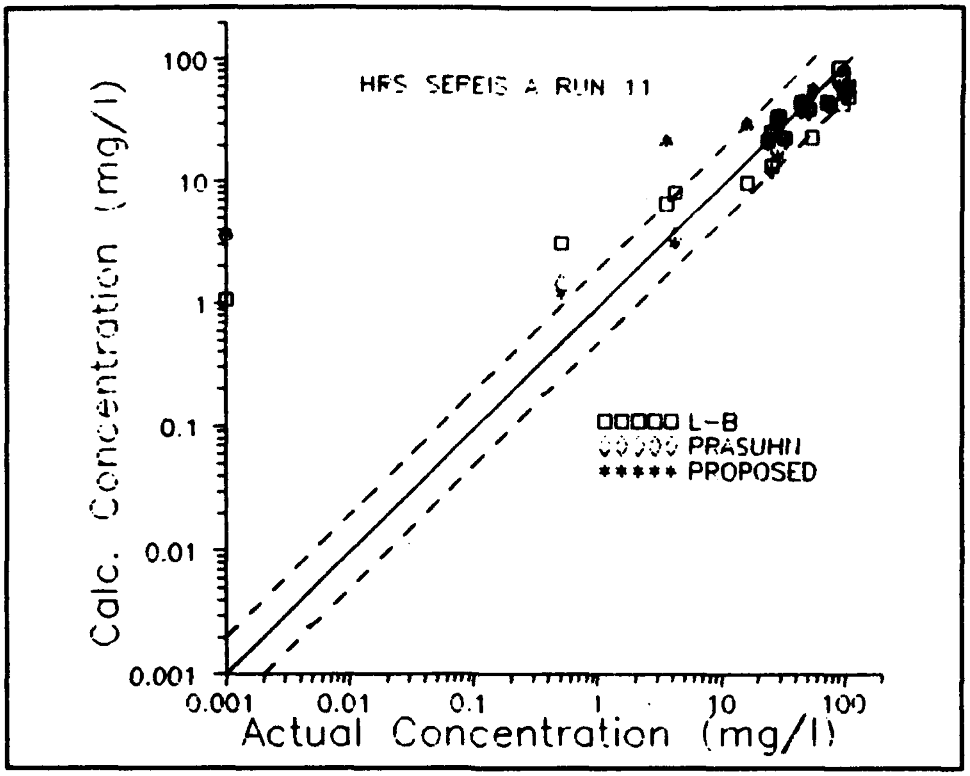

Figure 13. HRS Series A, Run 11, Concentration by Size Fractions

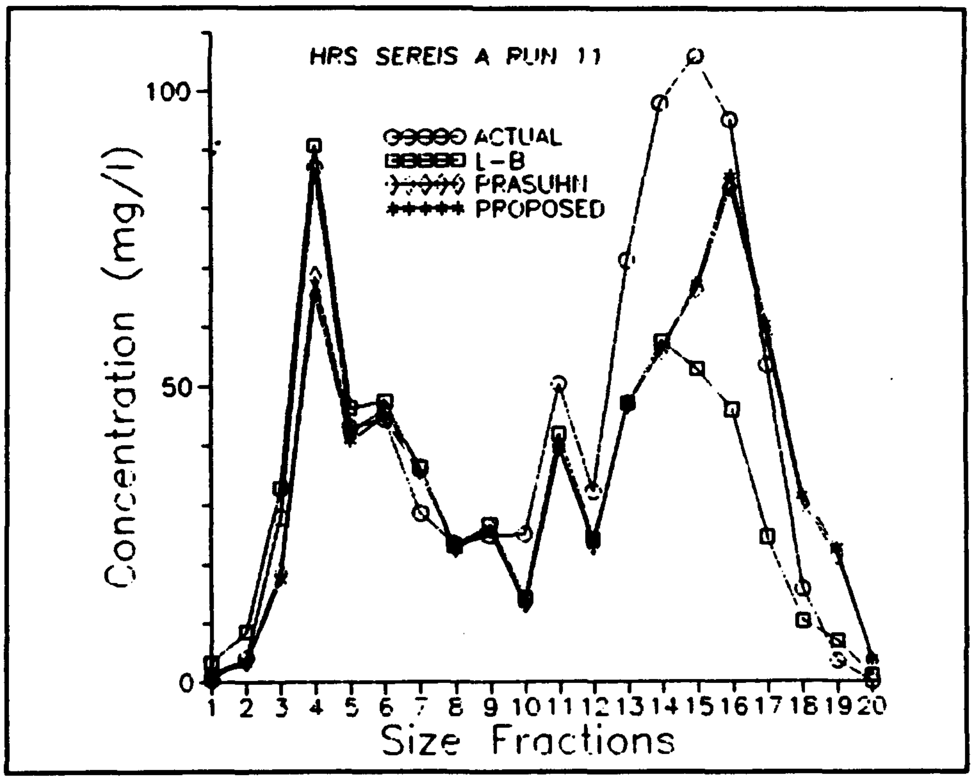

Figure 14. HRS Series A, Run 11, Concentration Size Fractions

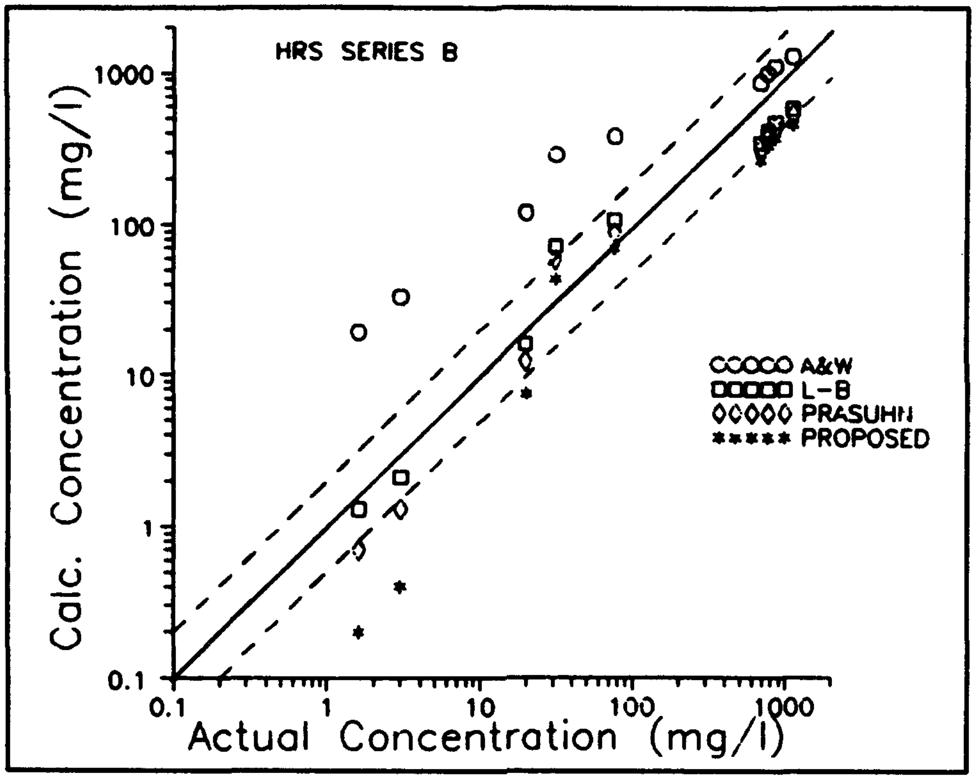

Figure 15. HRS Series B, Total Concentration

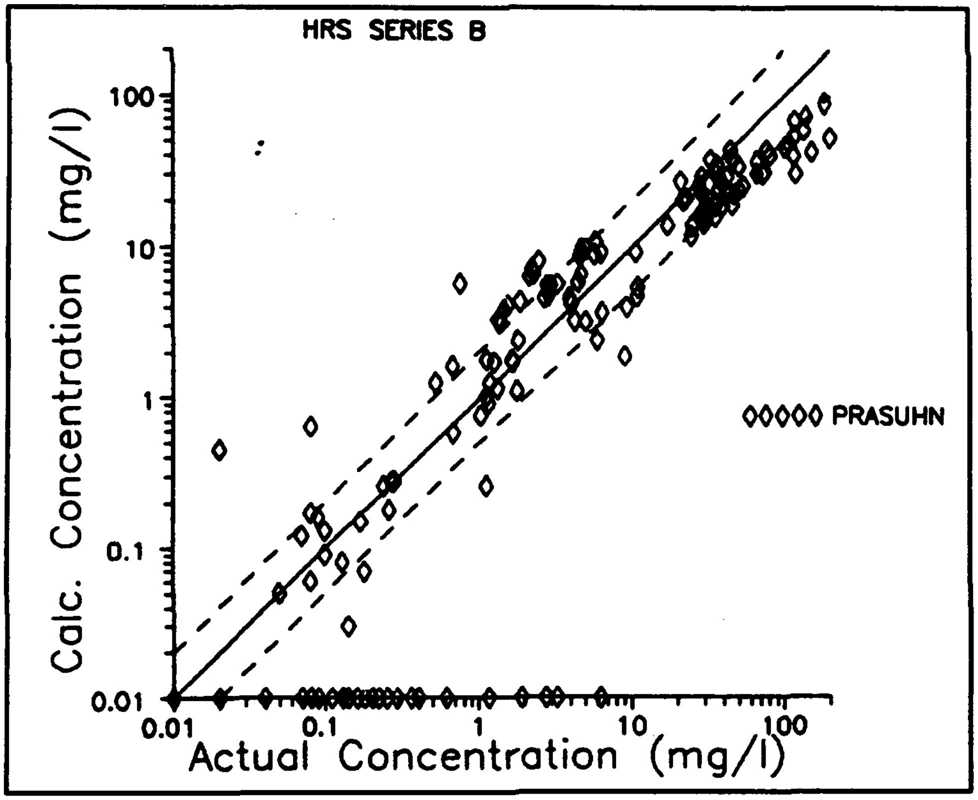

Figure 16. HRS Series B, All Runs, Concentration by Size Fractions

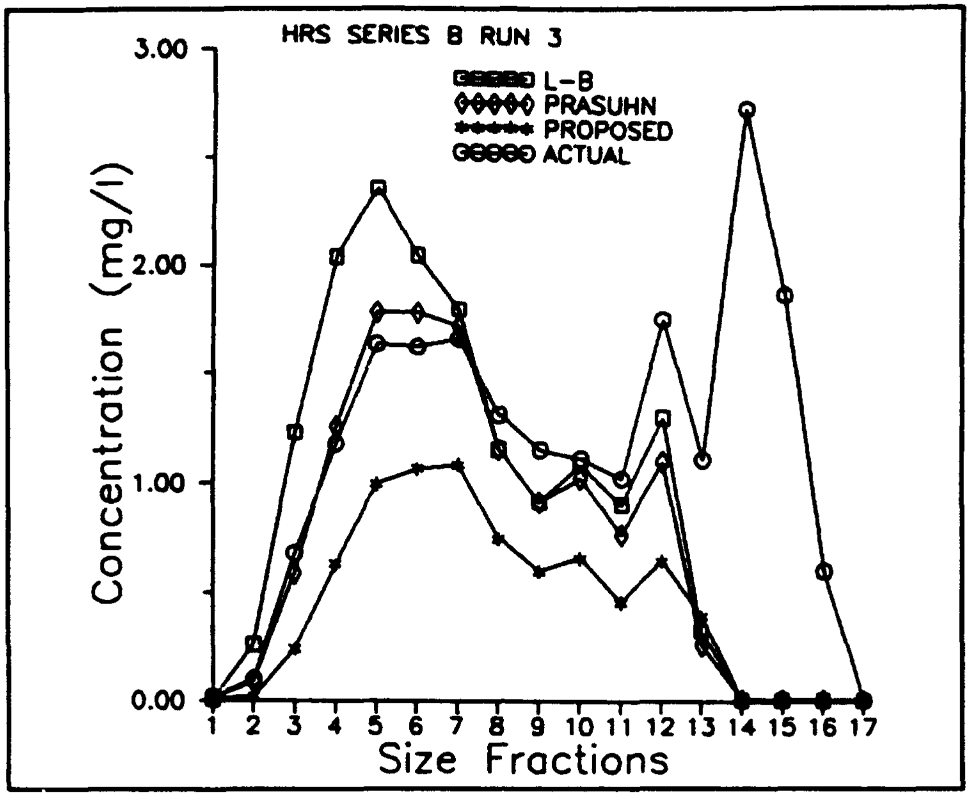

Figure 17. HRS Series B, Run 3, Concentration by Size Fractions

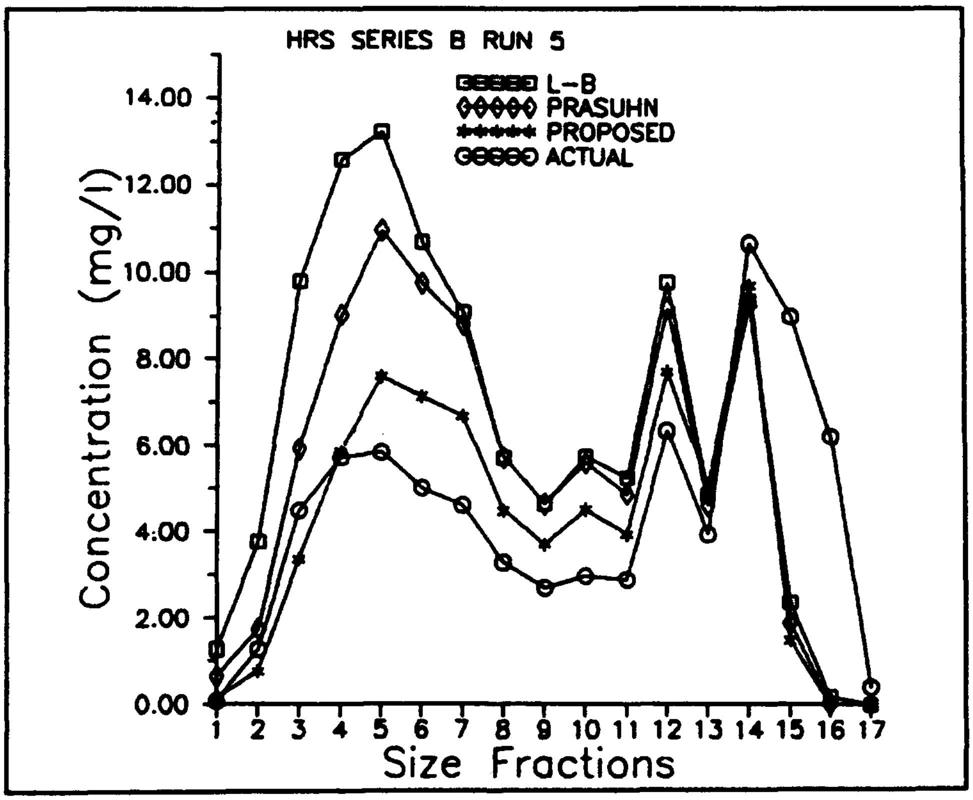

Figure 18. HRS Series B, Run 5, Concentration by Size Fractions

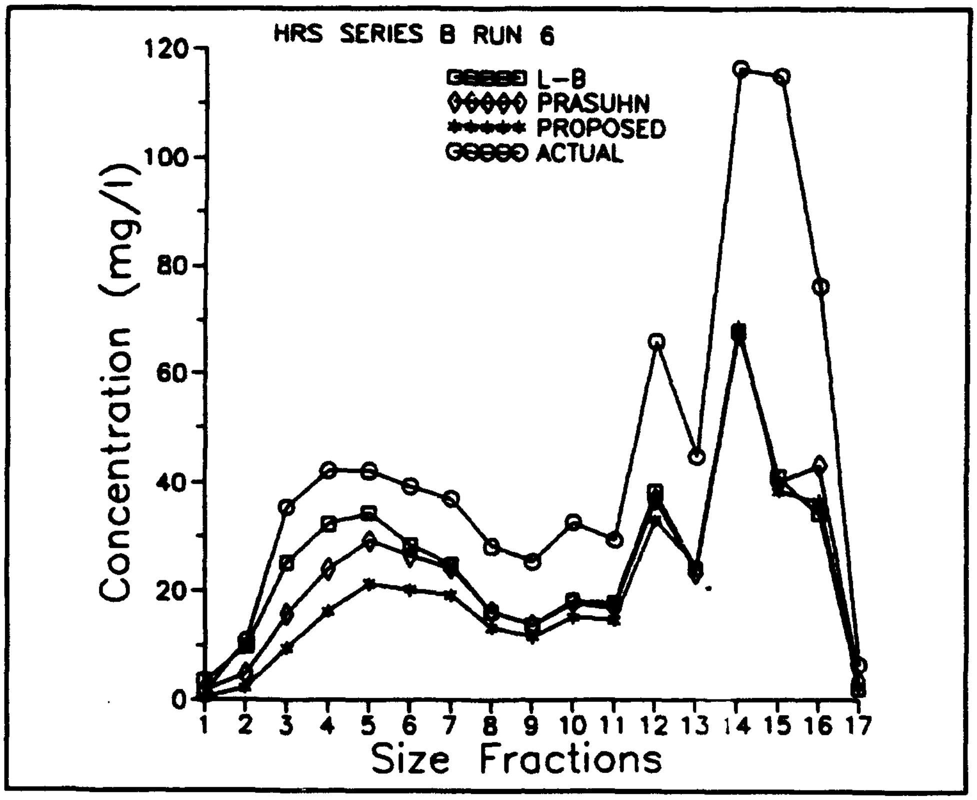

Figure 19. HRS Series B, Run 6, Concentration by Size Fractions

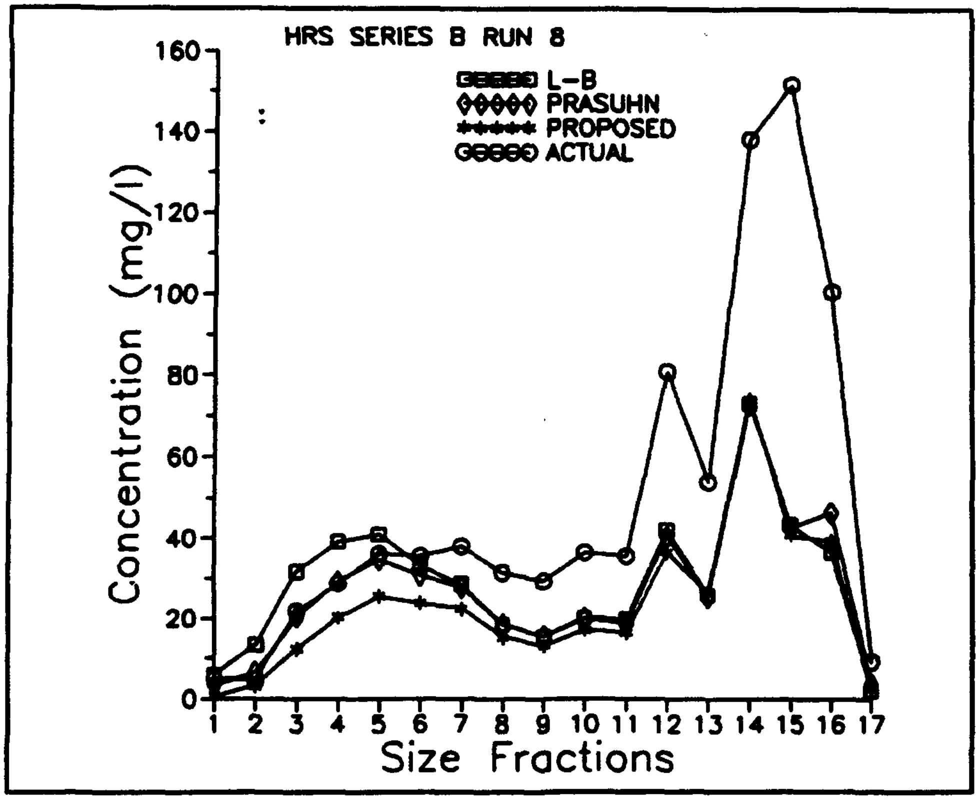

Figure 20. HRS Series B, Run 8, Concentration by Size Fractions

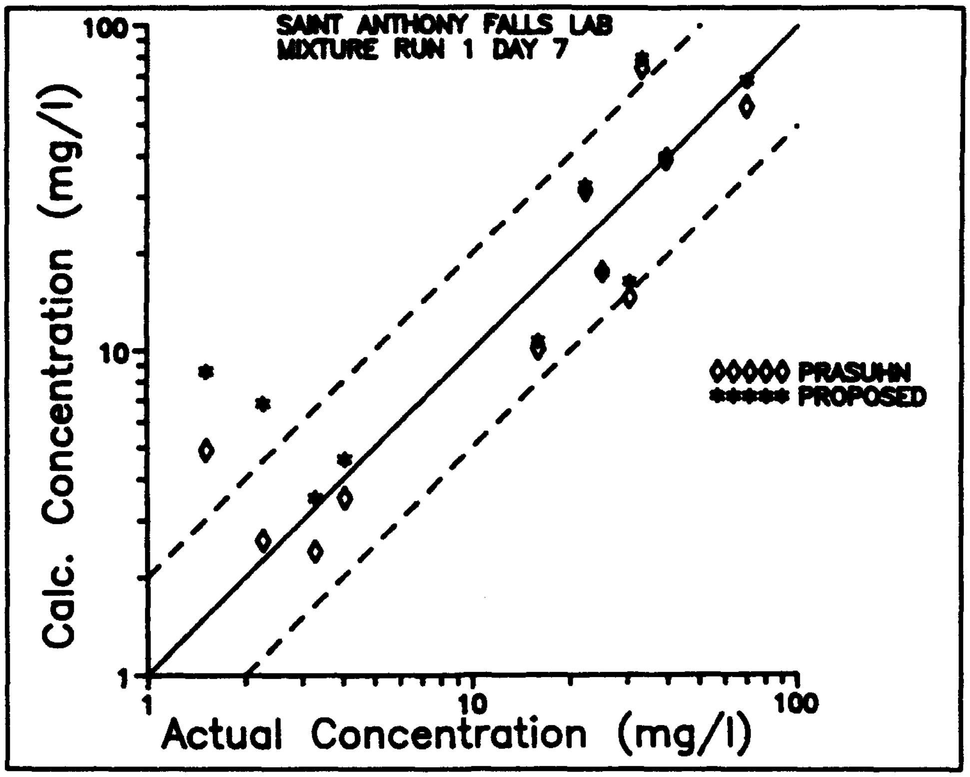

Figure 21. St. Anthony Falls, Run 1, Concentration by Size Fractions

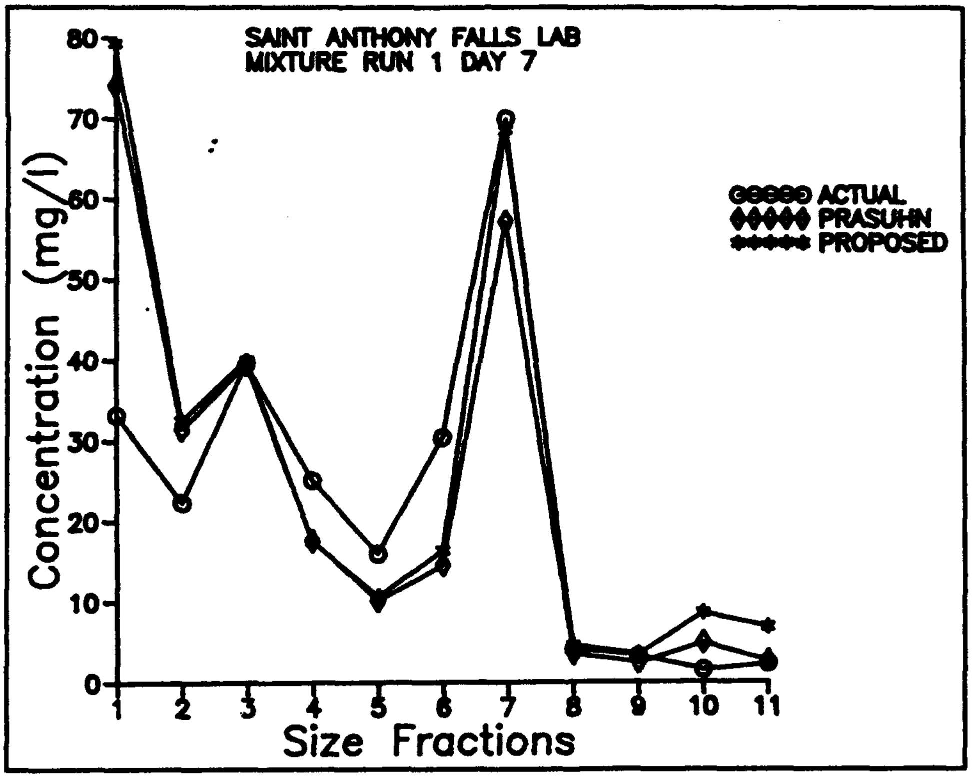

Figure 22. St. Anthony Falls, Run 1, Concentration by Size Fractions

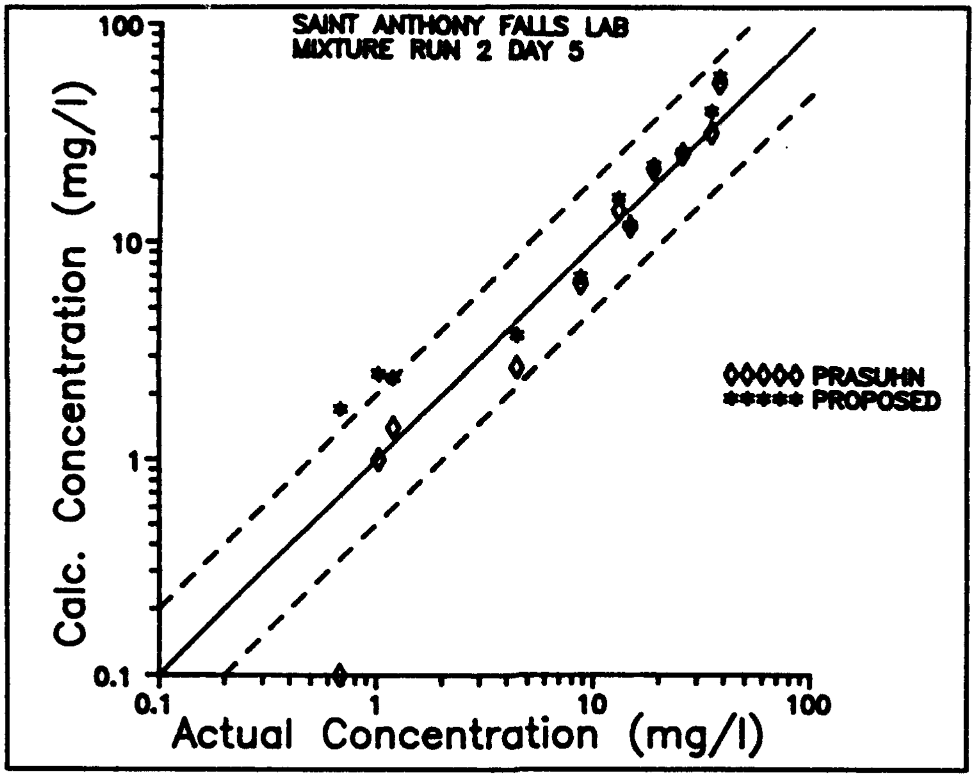

Figure 23. St. Anthony Falls, Run 2, Concentration by Size Fractions

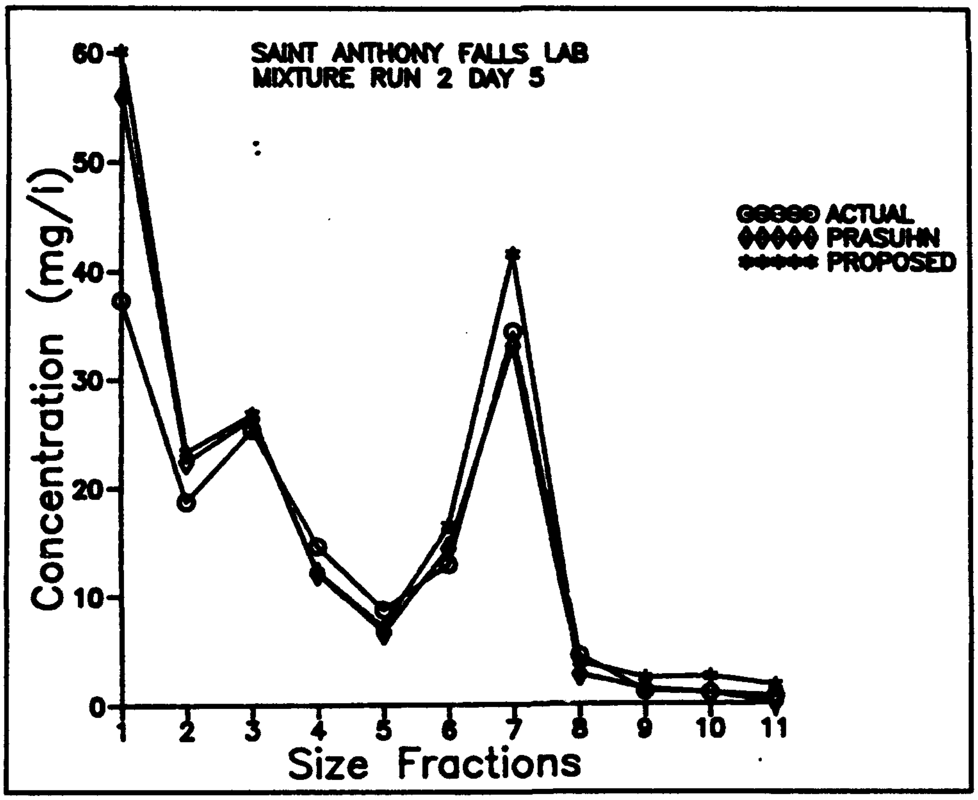

Figure 24. St. Anthony Falls, Run 2, Concentration by Size Fractions

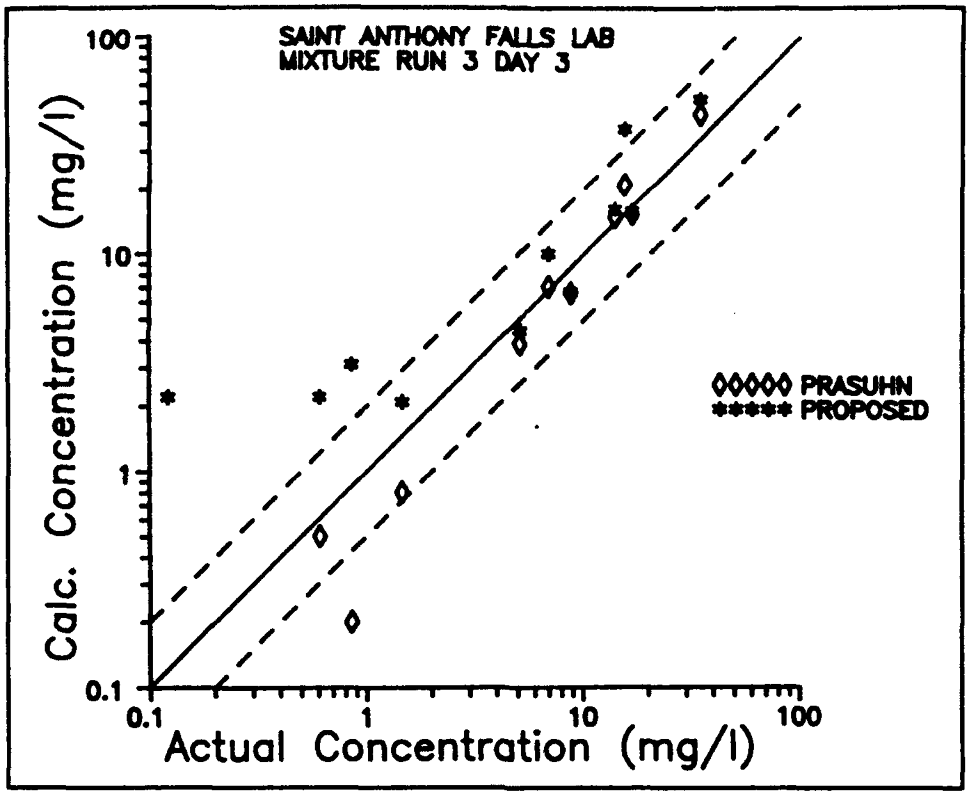

Figure 25. St. Anthony Falls, Run 3, Day 3, Concentration by Size Fractions

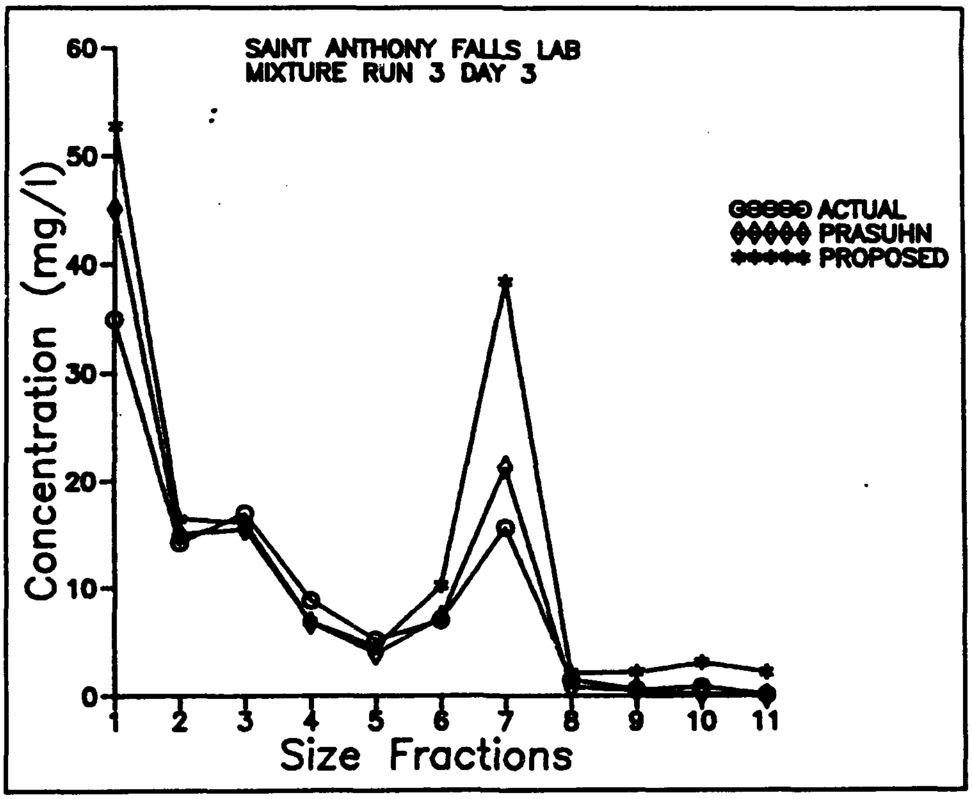

Figure 26. St. Anthony Falls, Run 3, Day 3, Concentration by Size Fractions

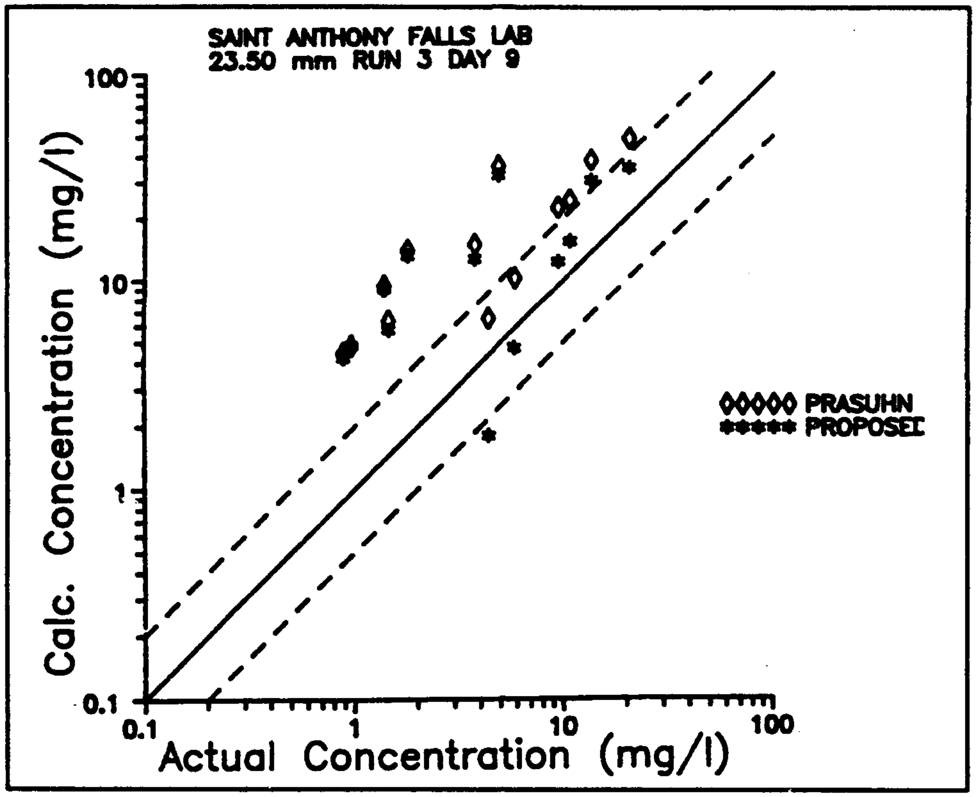

Figure 27. St. Anthony Falls, Run 3, Day 9, Concentration by Size Fractions

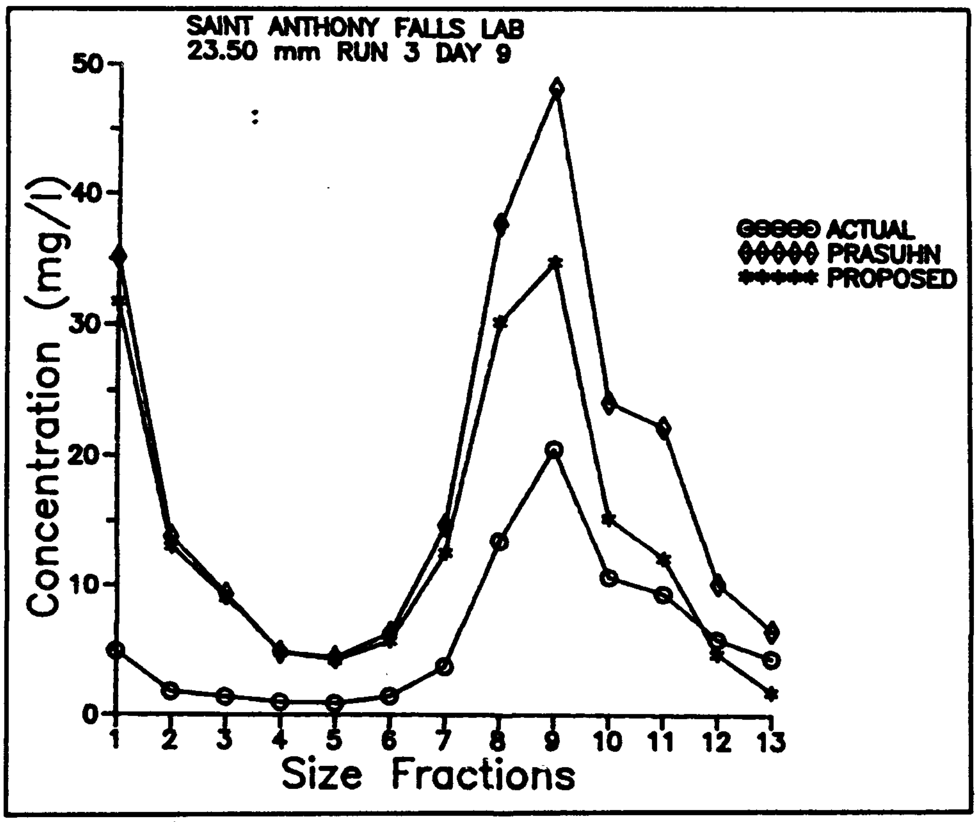

Figure 28. St. Anthony Falls, Run 3, Day 9, Concentration by Size Fractions

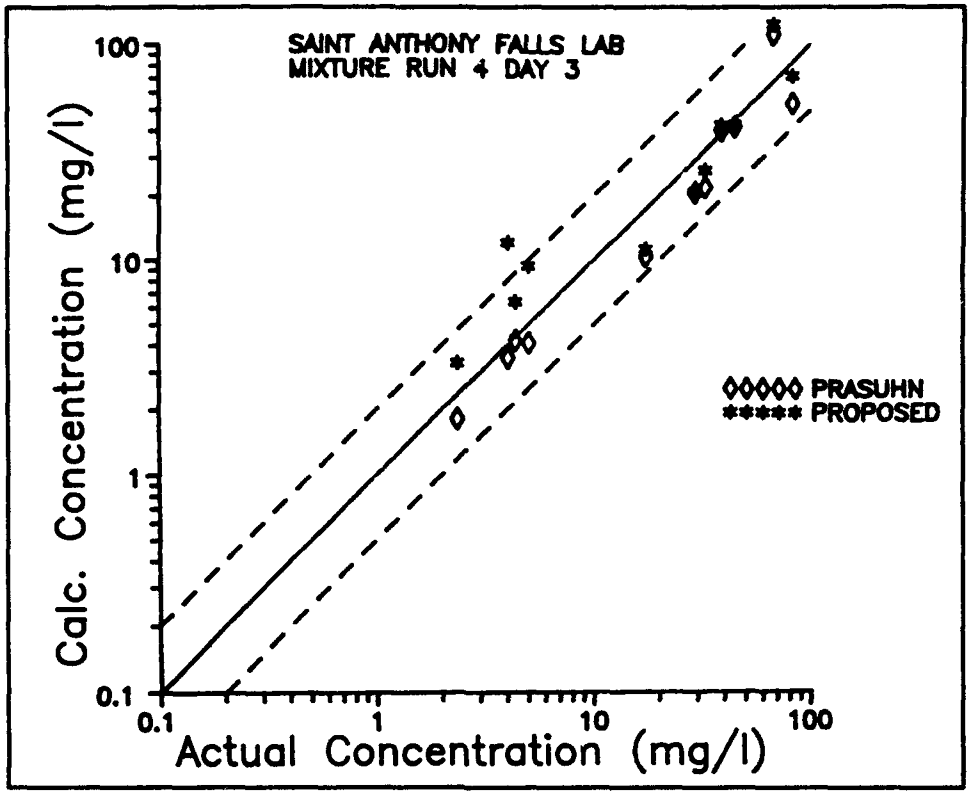

Figure 29. St. Anthony Falls, Run 4, Day 3, Concentration by Size Fractions

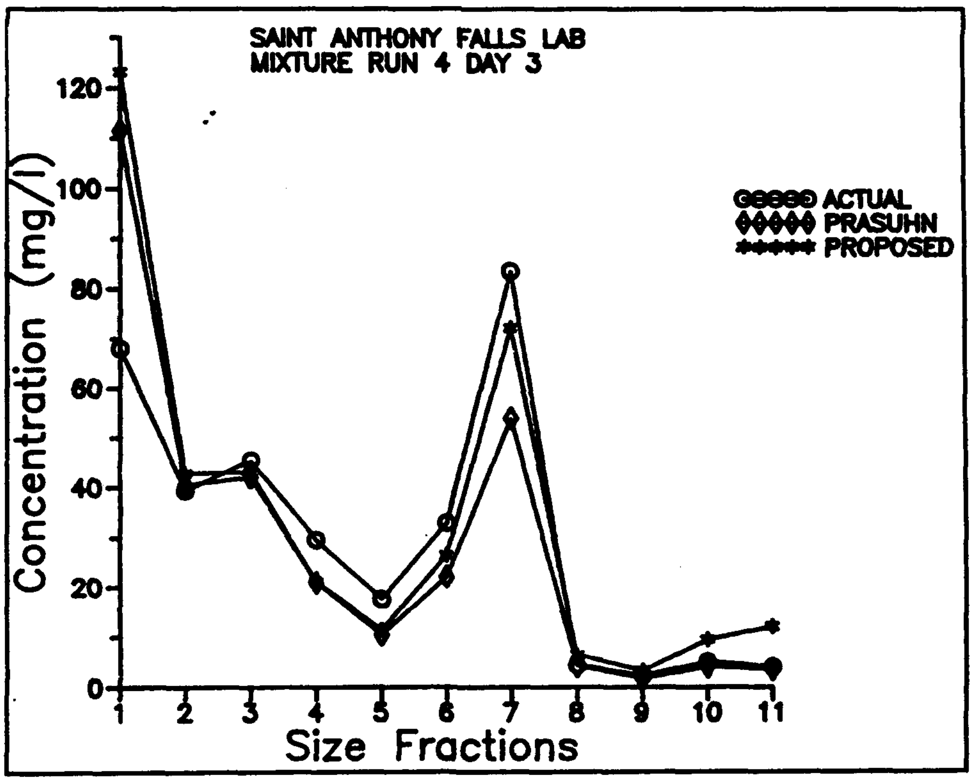

Figure 30. St. Anthony Falls, Run 4, Day 3, Concentration by Size Fractions

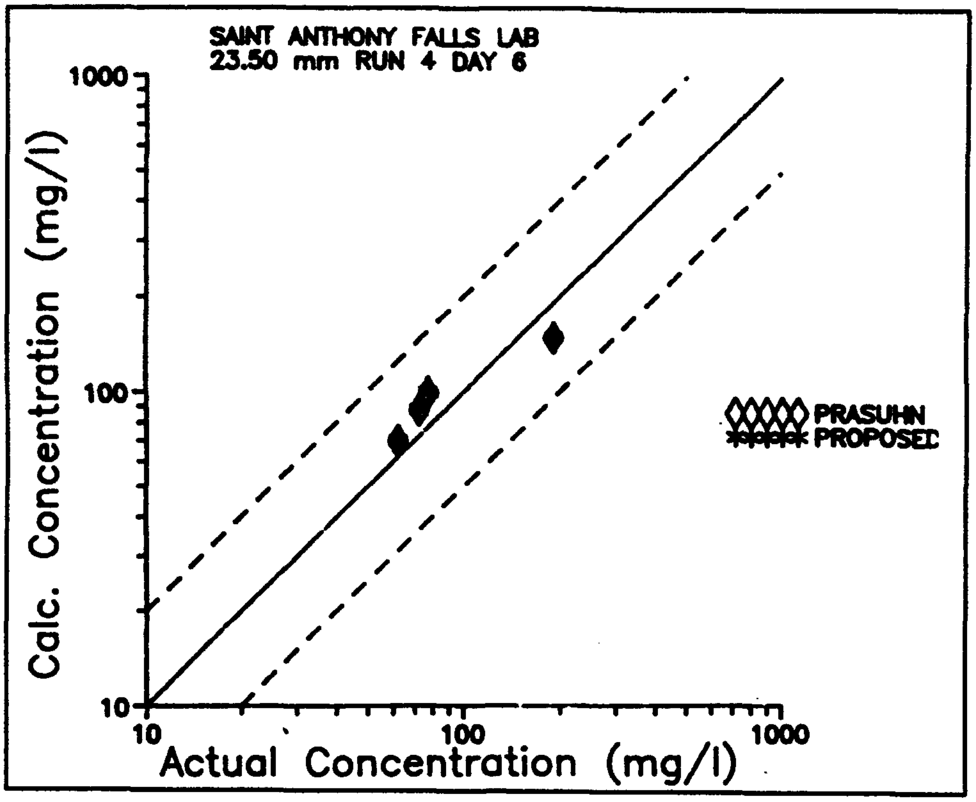

Figure 31. St. Anthony Falls, Run 4, Day 6, Concentration by Size Fractions

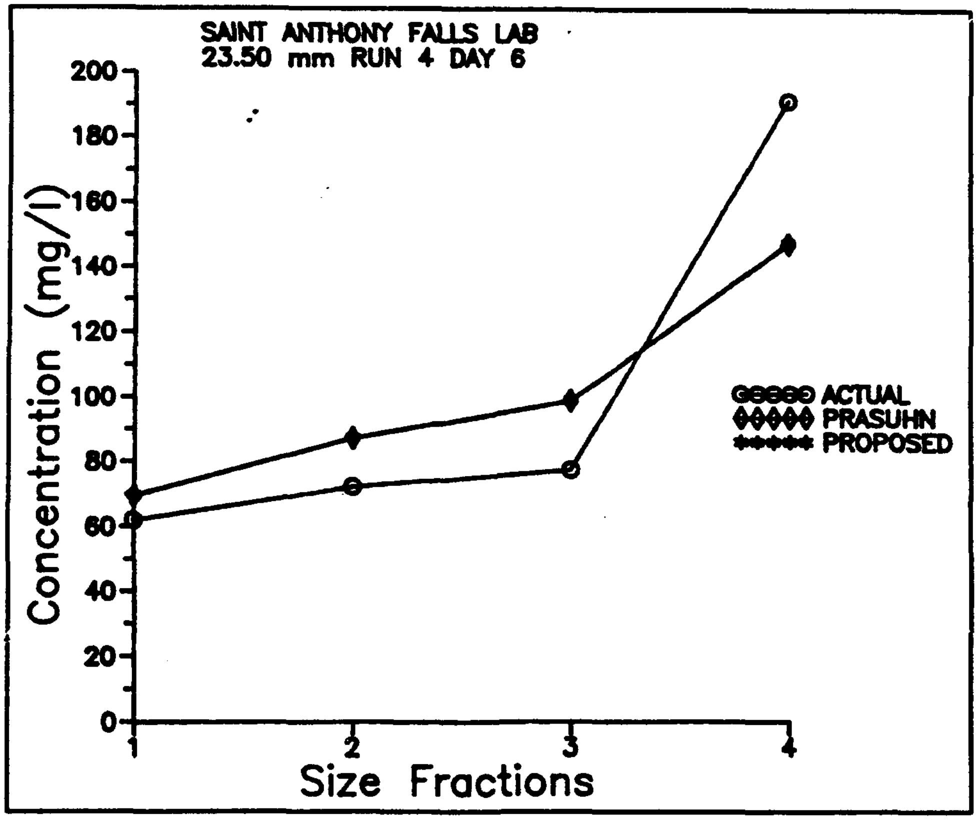

Figure 32. St. Anthony Falls, Run 4, Day 6, Concentration by Size Fractions

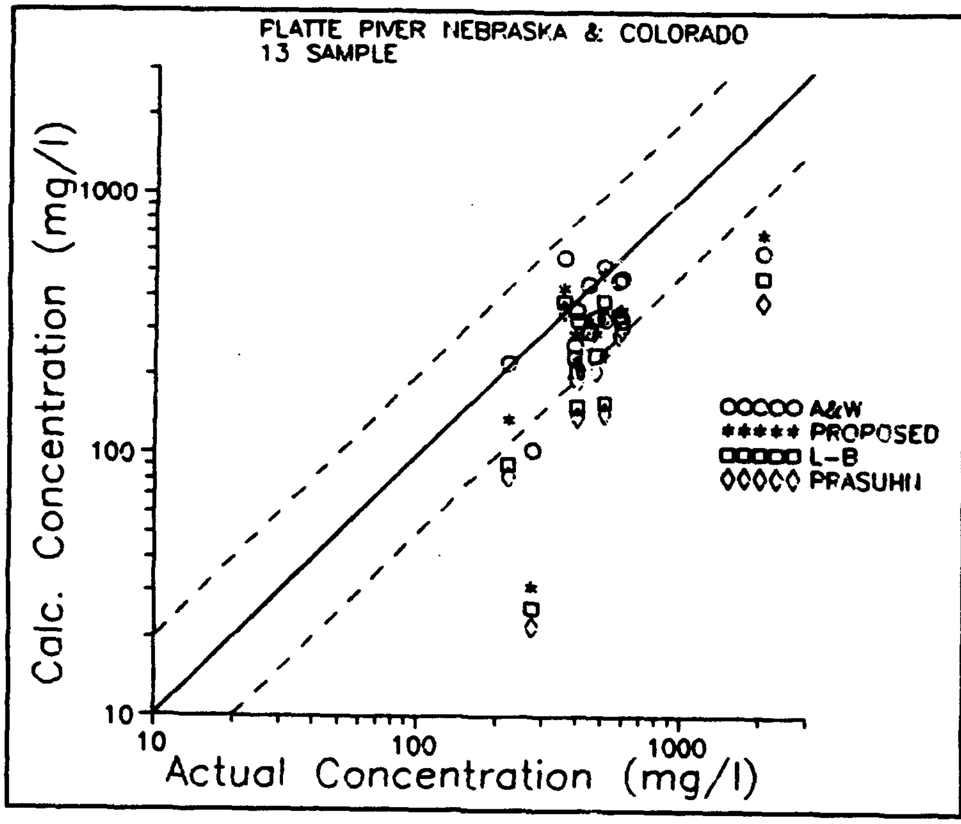

Figure 33. Platte River, Total Concentration

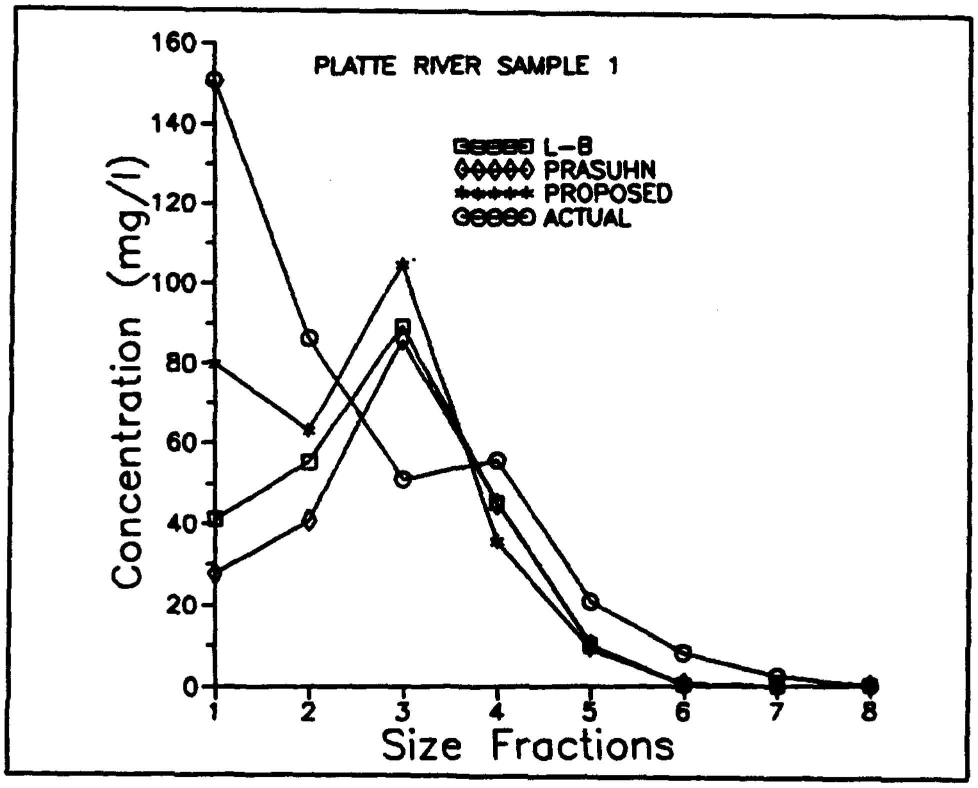

Figure 34. Platte River, Sample 1, Concentration by Size Fractions

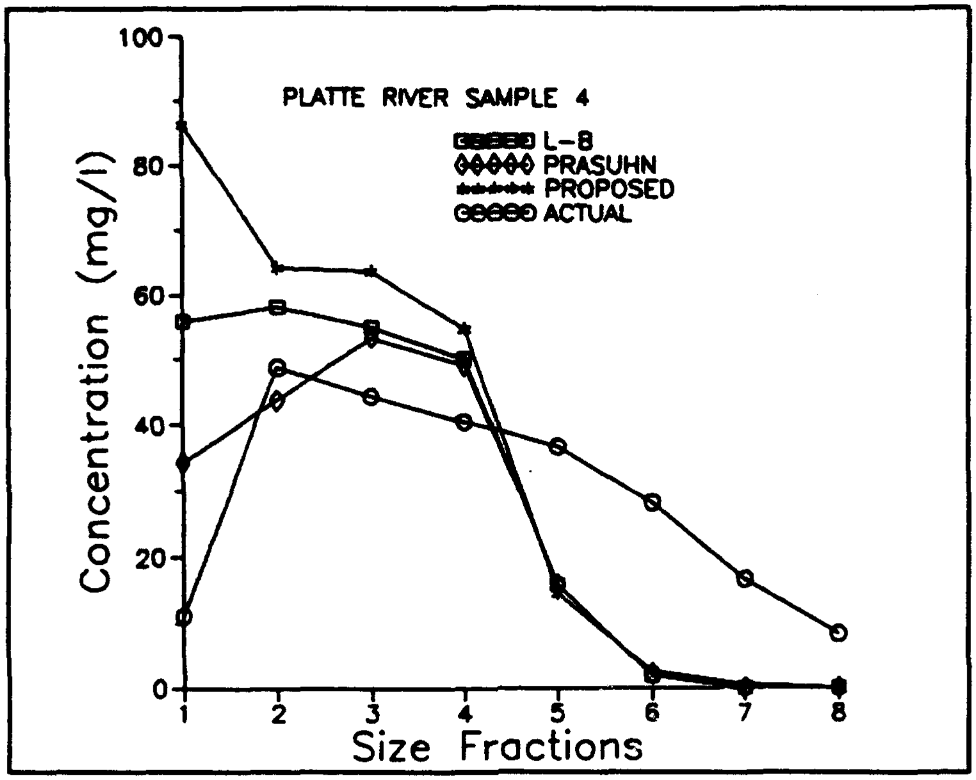

Figure 35. Platte River, Sample 4, Concentration by Size Fractions

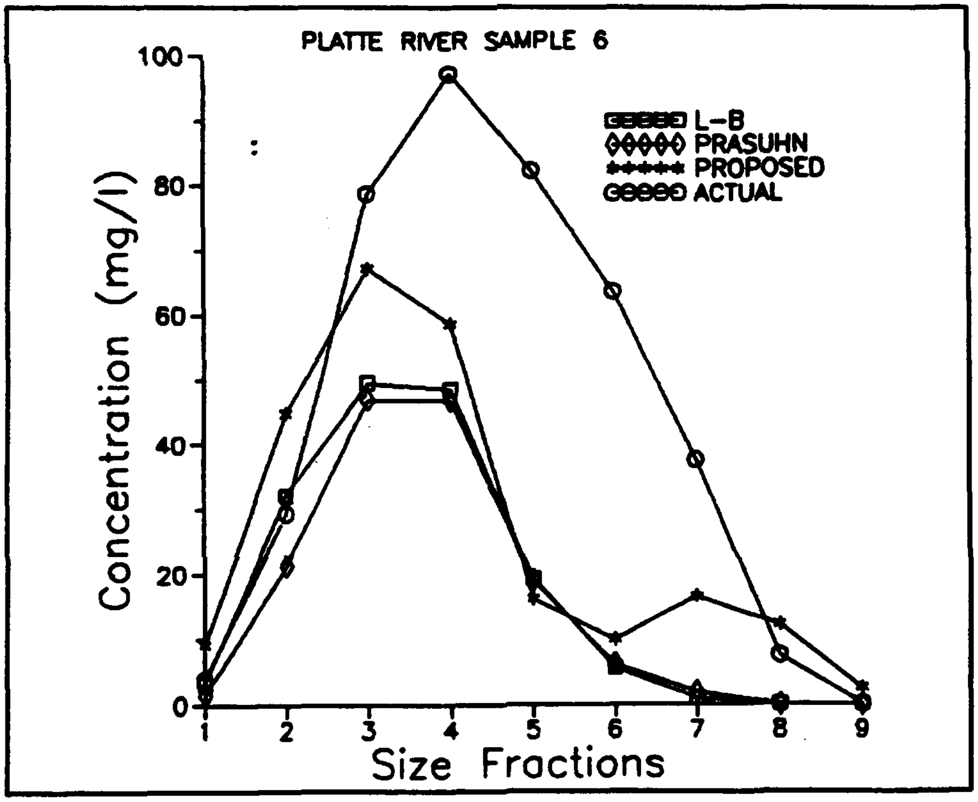

Figure 36. Platte River, Sample 6, Concentration by Size Fractions

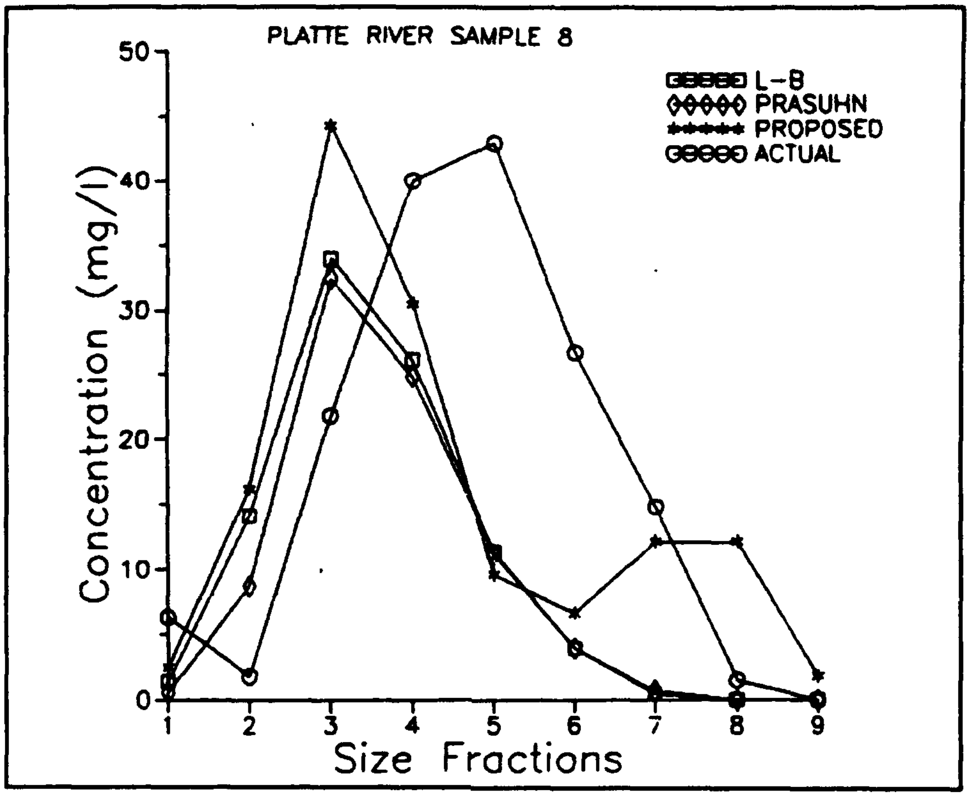

Figure 37. Platte River, Sample 8, Concentration by Size Fractions

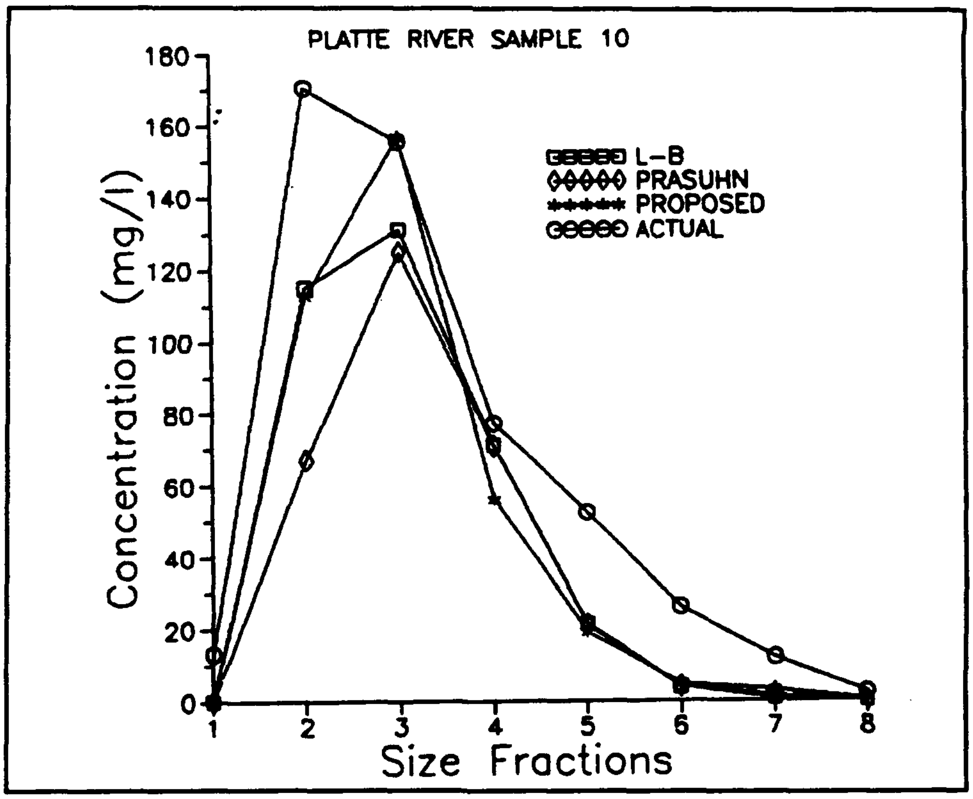

Figure 38. Platte River, Sample 10, Concentration by Size Fractions

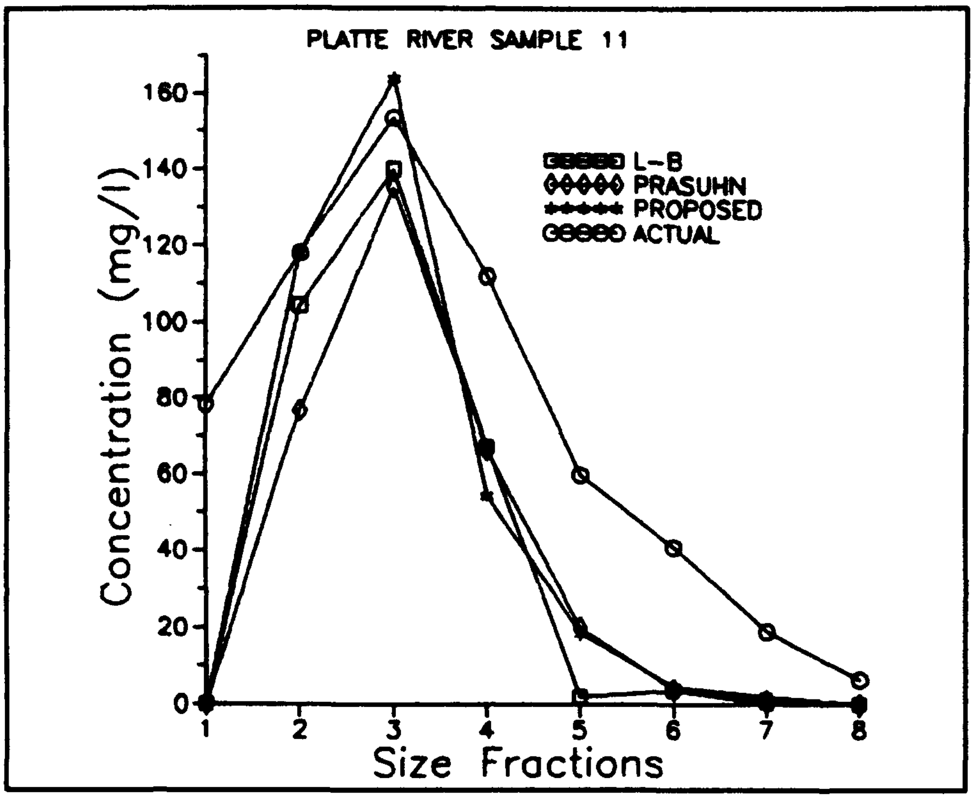

Figure 39. Platte River, Sample 11, Concentration by Size Fractions

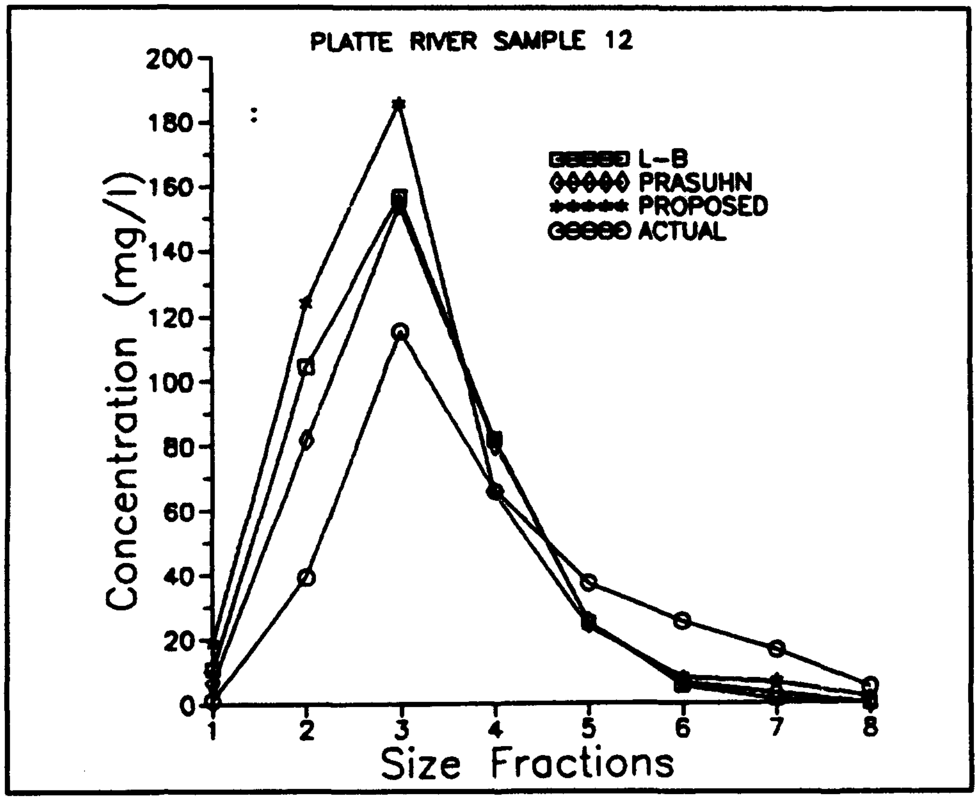

Figure 40. Platte River, Sample 12, Concentration by Size Fractions

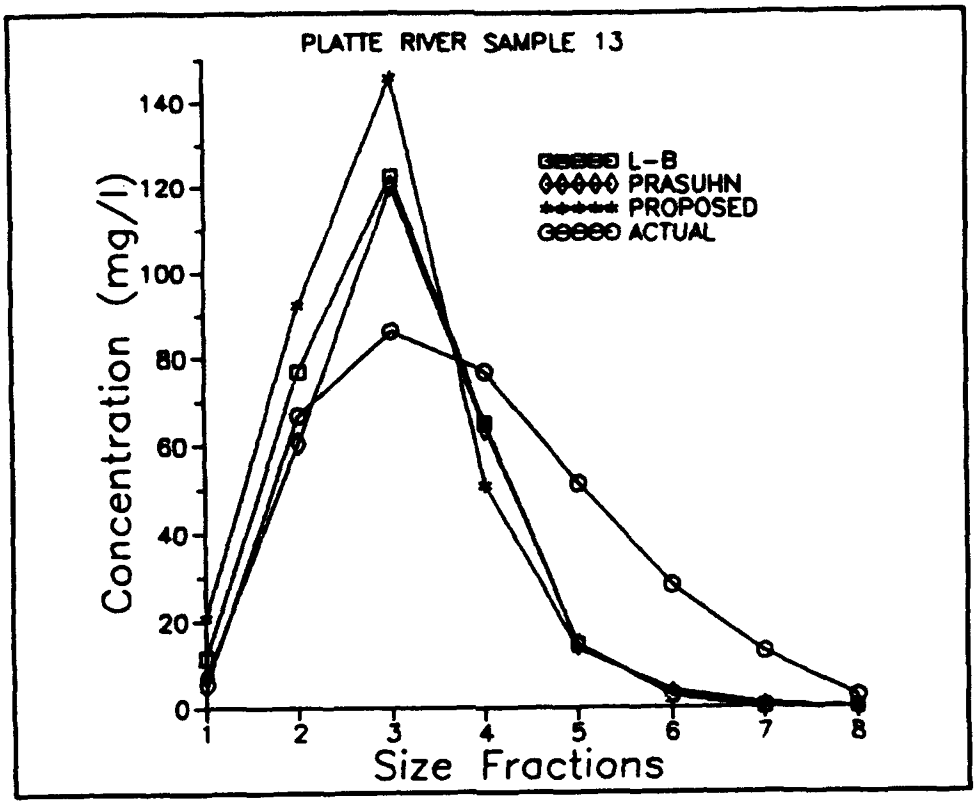

Figure 41. Platte River, Sample 13, Concentration by Size Fractions

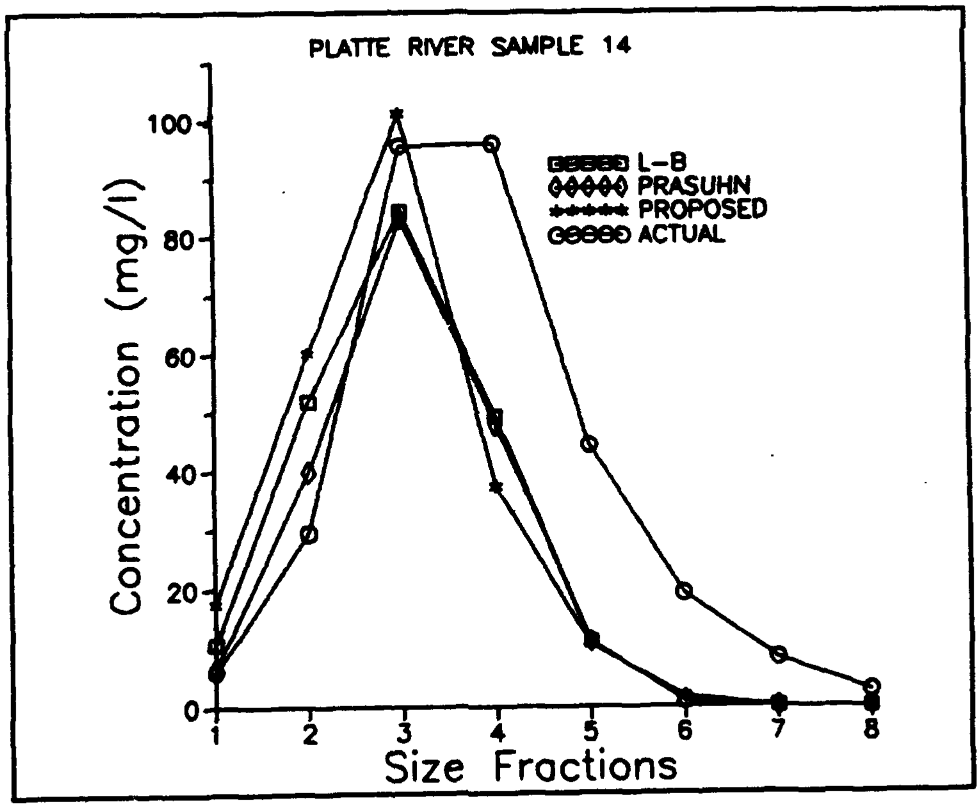

Figure 42. Platte River, Sample 14, Concentration by Size Fractions

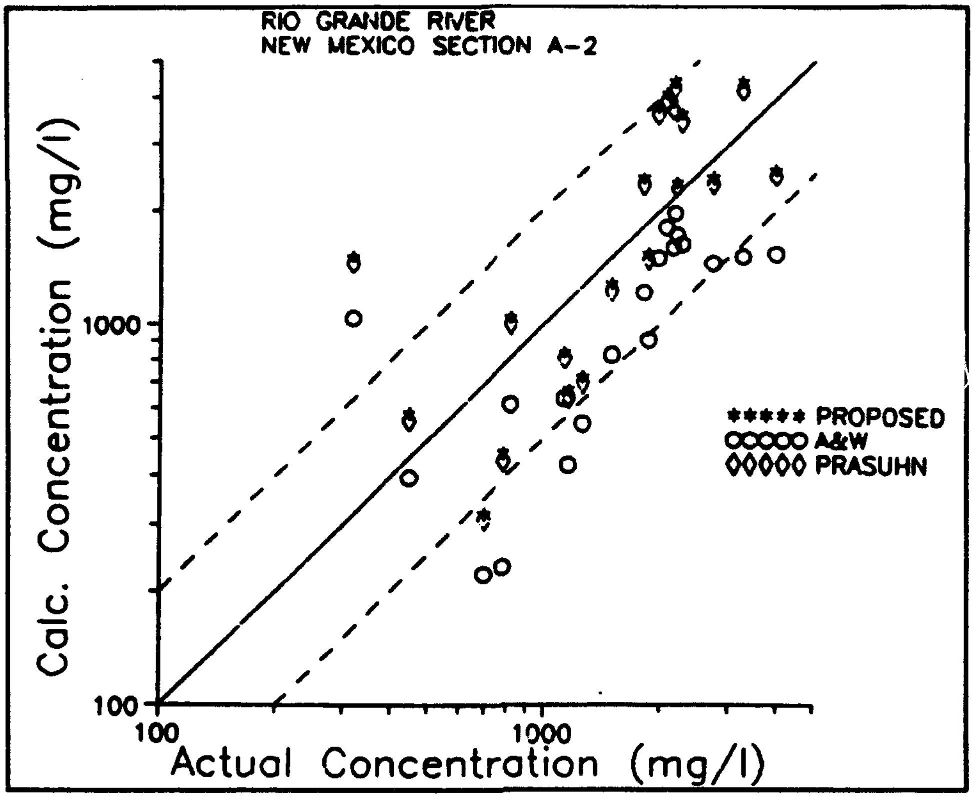

Figure 43. Rio Grande River, Section A-2, Total Concentration

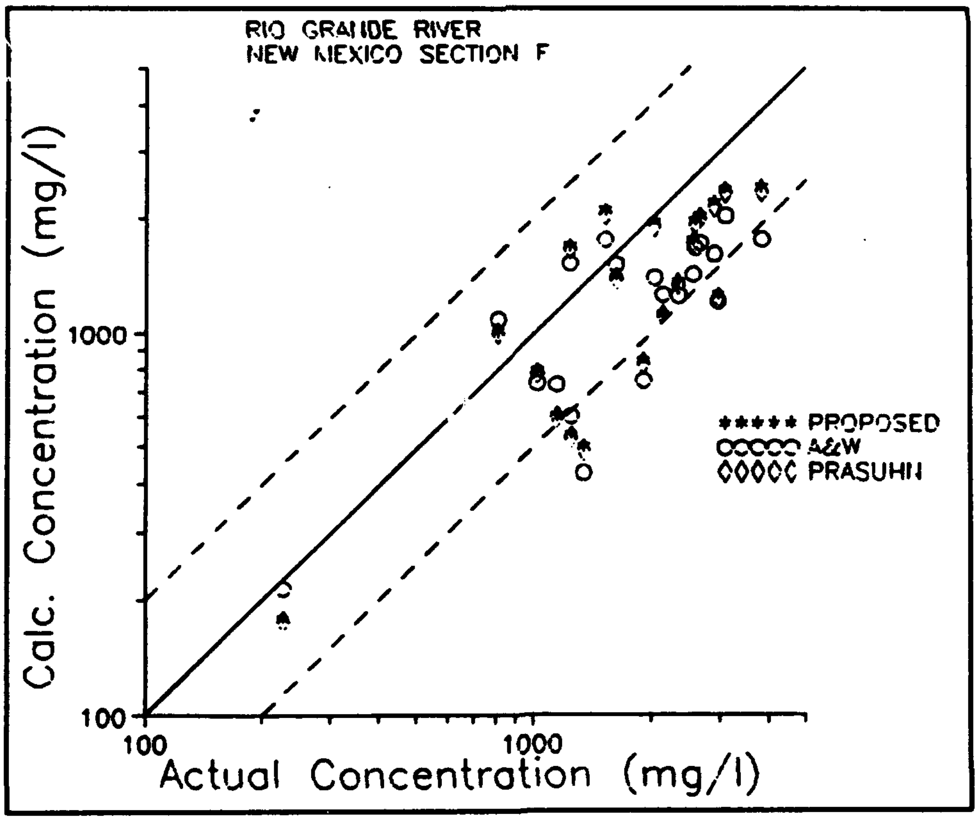

Figure 44. Rio Grande River, Section F, Total Concentration

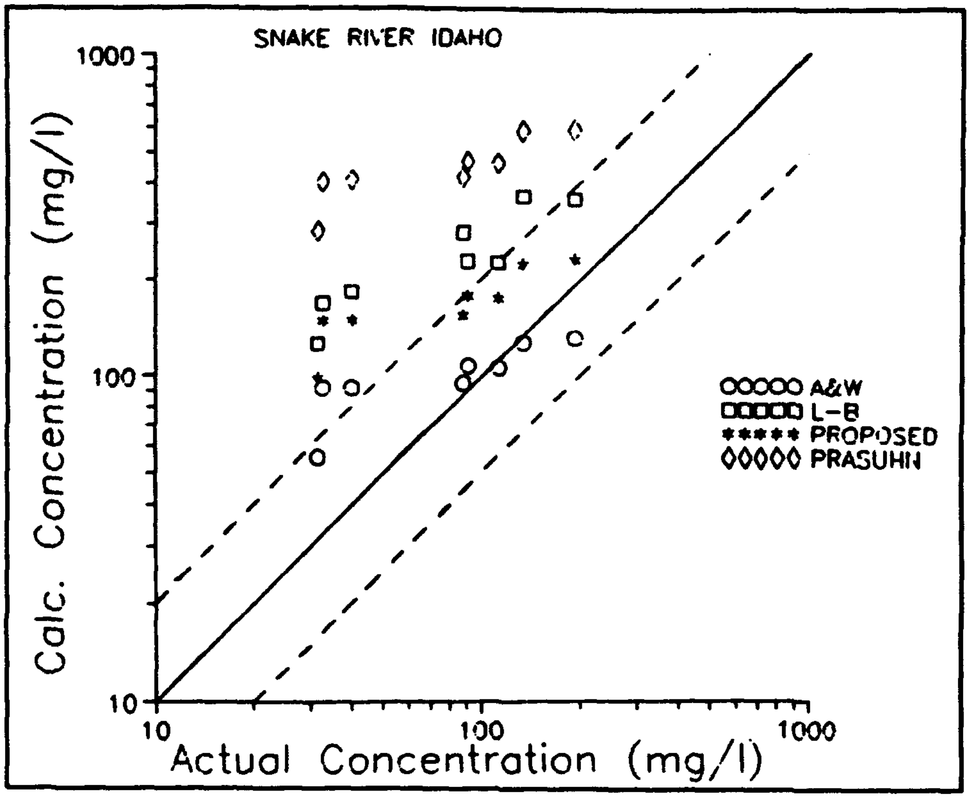

Figure 45. Snake River, Total Concentration

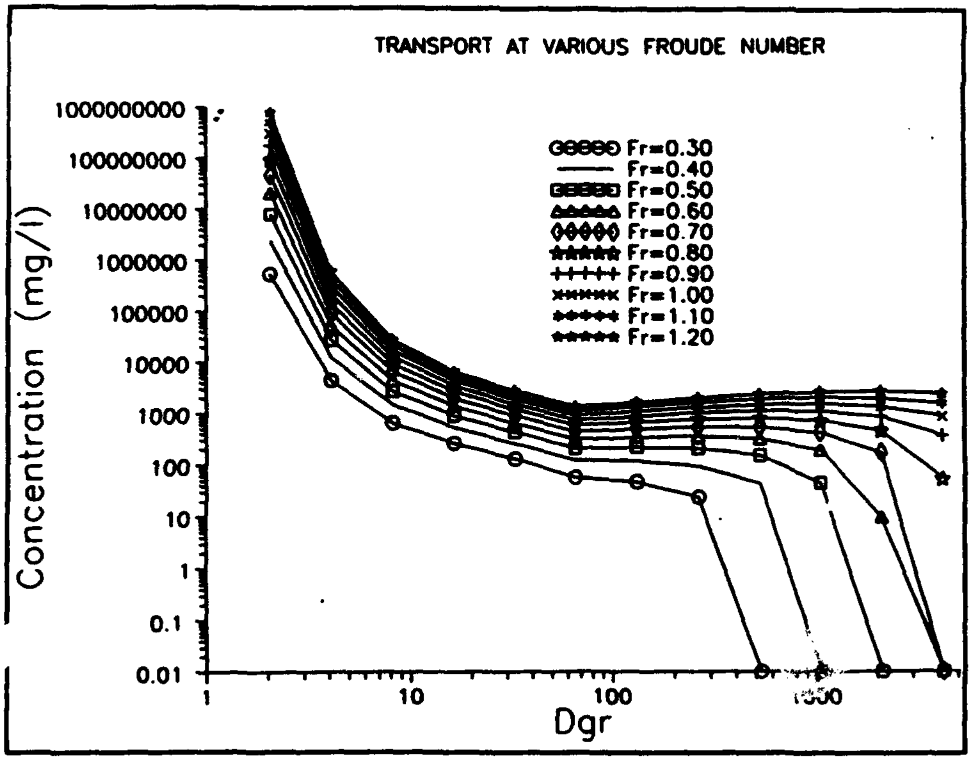

Figure 46. Concentration Distribution as a Function of the Froude Number

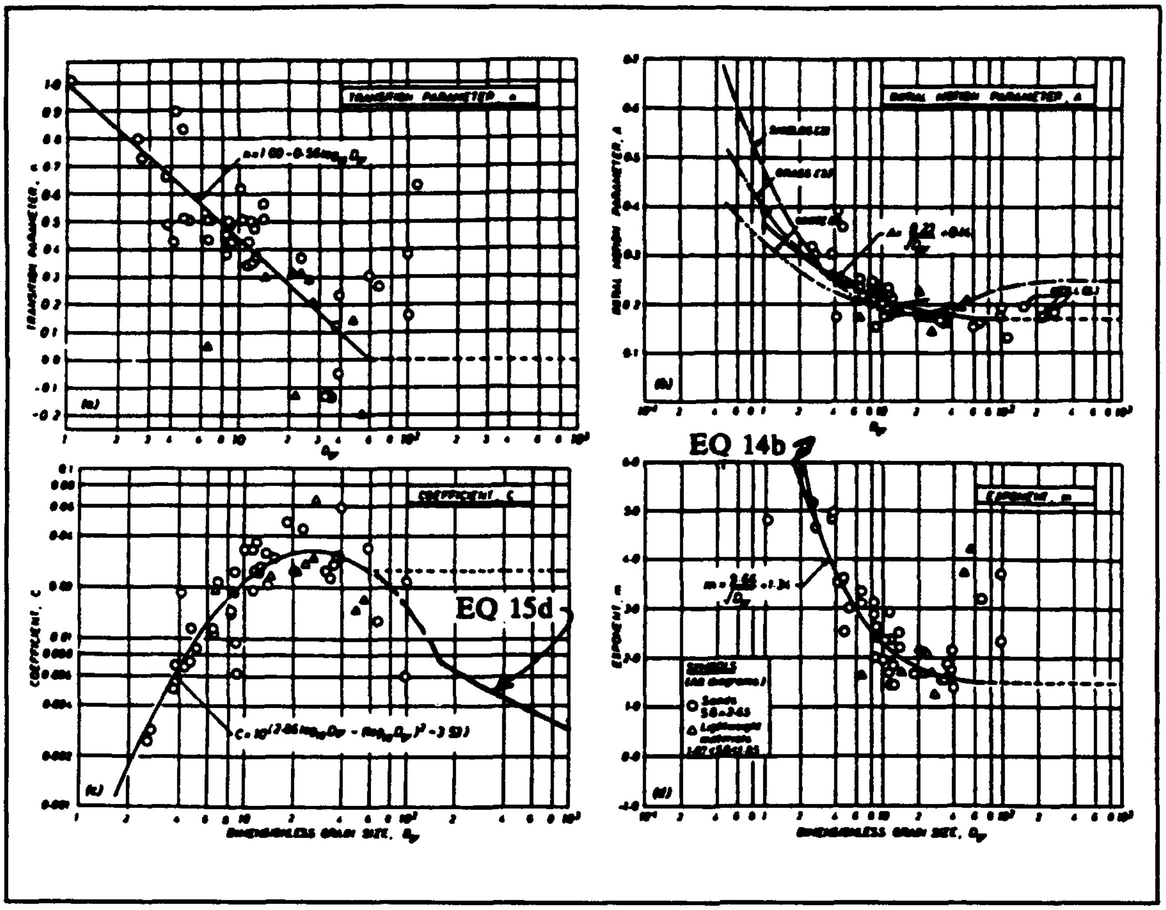

Figure 47. Ackers and White (1973) Figure 3

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13. ABSTRACT *(Maximum 200 words)*

This report documents modifications to the original Ackers-White sediment transport function to calculate sediment transport by grain size classes, to include the new routine in HEC-6, and to increase the number of grain size classes into the cobble-boulder range.

The Ackers and White sediment transport procedure gives a total bed material load for a sediment mixture based on the representative particle size of the mixture. The dimensionless transport G_{gr} is calculated from the mobility factor F_{gr} according to

$$G_{gr} = C(F_{gr}/A - 1)^m$$

Ackers and White did not suggest that their procedure could be used to calculate transport by size fractions.

This research extended the calculations to particle size classes by modifying the m and C coefficients.

(Continued)

14. SUBJECT TERMS			15. NUMBER OF PAGES
Ackers and White	Cobbles	Sediment mixtures	65
Bed material load	HEC-6		16. PRICE CODE
Boulders	Multiple grain sizes		

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The existing subroutine ACKER should continue to be used in HEC-6 with changes made to the equations for m and C as given in Equations 14b and 15d in this report. In the cases tested, this study demonstrates a significantly improved function when the bed distribution is broadly graded. However, it should be tested in HEC-6 using additional, more diverse data sets.

This modified function can be applied to particle sizes up through cobbles. It still remains, of course, to find a transport function for boulder size sediments. If HEC-6 is used for the transport of boulders, care should be taken to consider the reasonableness of the results.

No matter which version of Ackers-White is used, the argument of the log function in the expression for the mobility factor (Equation 1) must remain greater than zero, i.e., $y/d_s > 0.1$. This should be included in any code involving Ackers-White.